Europa Orbiter

Mission and Project Description

EUROPA ORBITER
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1. Introduction

This document provides background information about the Europa Orbiter mission and pointers to the present body of relevant scientific knowledge. This information is to be used in conjunction with Appendices A, B, E, and F by proposers in preparing a formal response to the Outer Planets Program Announcement of Opportunity.

This document contains general information, requirements, technical descriptions, and performance and interface envelopes that are pertinent to the preparation of proposals in response to the Europa Orbiter part of the AO. Also given is a detailed description of the activities for which the selected Principal Investigators (PIs) and Team Members will be responsible. Information from the AO is repeated only if necessary for continuity of content. In the event of conflict between the provisions of AO and this document, the AO takes precedence.

It is important to note that the reference mission described here is only one of several options under study. This AO will result in the selection of Europa Orbiter Science Investigations, the leaders and members of which will become members of the Europa Orbiter Integrated Implementation Team.

The science investigations proposed by the winning teams, as well as the reference mission described in this document, will evolve together into an end-to-end mission that best meets the science objectives within the constraints of the program. The actual Europa Orbiter mission that is implemented may differ substantially from the reference mission and the details of the winning science investigation proposals.

NASA has not committed to this project, nor this reference mission, nor to any specific launch schedule, launch vehicle, power source, Project budget, or funding profile. In addition, the spacecraft design depicted in this AO is a conceptual, strawman design. It is likely to change during the spacecraft and payload definition phase (prior to Science Confirmation) when science and engineering teams can interact and best meet the science objectives within the constraints of the program.

The word "mission" means the Europa Orbiter mission. "Spacecraft" includes all launched engineering hardware and software. The term "flight system" includes all launched hardware and software for both engineering and science functions. The term "Europa Orbiter" may be used to refer either to the spacecraft itself or to the Europa Orbiter mission (as in "…will be developed for Europa Orbiter"). The word "project" is used in this document to refer to the Outer Planets/Solar Probe Project; Europa Orbiter is one of the three missions assigned to this Project.

2. Overview

2.1 Science Objectives

2.1.1 Mission Overview

The Europa Orbiter mission will deliver a spacecraft into low orbit about Jupiter's moon Europa to investigate the question of whether or not a liquid water ocean currently exists under its frozen surface and to characterize Europa for possible future exploration. This mission will allow fundamental questions to be addressed concerning the history of this unique satellite and the possibility that Europa has now or in the past harbored a habitat hospitable to life. The Galileo mission has provided circumstantial evidence that such an ocean did exist, at least at one time in the past.

The reference mission calls for the November 2003 launch of a single spacecraft on a direct trajectory to Jupiter. The spacecraft is captured into orbit about Jupiter where a series of a dozen or more gravity assists from close satellite flybys are used to extract energy from the trajectory in preparation for insertion into orbit about Europa.

The reference orbit about Europa will be at high inclination to facilitate nearly global coverage by the ground track and at low altitude (~200 km) to provide high spatial resolution sampling. The Project may chose to investigate orbits with lower inclinations for the purposes of mitigating planetary protection requirements (see the Europa Orbiter Preliminary Planetary Protection Requirements document of the Outer Planets Program Library, available over the Internet through URL http://outerplanets.LaRC.NASA.gov/outerplanets). Proposed investigations should be based on the reference, high-inclination orbit but should include a brief analysis of effects of adopting a 45° (or 135°) orbit inclination (see Section 2.2.1.4).

The nominal duration in Europa orbit is 30 days, which provides for about 300 orbits around the satellite. The intense radiation field in Jupiter's magnetosphere at the distance of Europa's orbit limits the lifetime of this mission and presents an engineering challenge to design survivable systems within the severe mass constraints of the mission.

A strawman science payload has been used to create a conceptual design of the mission and spacecraft. This strawman payload includes an imaging system, a laser altimeter, and a radar sounder, along with the usual radio science measurement capability provided by the spacecraft telecommunications subsystem. Measurements might include radar sounding of the thickness of Europa's surface ice layer, radiometric doppler tracking for gravity field determination, multispectral imaging of global and local surface features, and laser altimeter measurements of the precise shape of the body including the bulge produced by Jupiter tides. These measurements should permit a clearer picture of the interior structure and geologic history of Europa. The actual payload, selected based on proposals received in response to this AO, could be substantially different from the strawman payload.

Europa Orbiter operations at Jupiter will consist of three phases: (1) Satellite Tour: The "Galileo-like" ballistic phase following Jupiter Orbit Insertion (JOI), expected to last approximately 1-2 years; (2) End Game: Final Europa encounters and associated maneuvers necessary to achieve Europa orbit, expected to last approximately 5 months; and (3) Europa Orbit: A precessing high-inclination circular orbit of Europa at altitudes between 100 km and 200 km, with a nominal mission lifetime of 1 month.

2.1.2 Science Objectives

The Europa Science Definition Team carefully considered the range of science objectives appropriate to a first detailed orbital mission to Europa. These were then prioritized, and their final ranking, endorsed by the Solar System Exploration Subcommittee and edited for use in this AO, appears below. Group 1 objectives are considered to have the highest priority for the first orbital mission; Group 2 objectives are considered important but not of the highest priority.

The groupings resulted in a scientifically compelling set of focused goals for a Europa Orbiter mission:

Group 1 Objectives:

- Determine the presence or absence of a subsurface ocean;
- Characterize the three-dimensional distribution of any subsurface liquid water and its overlying ice layers; and
- Understand the formation of surface features, including sites of recent or current activity, and identify candidate landing sites for future lander missions.

Group 2 Objectives:

- Characterize the surface composition, especially compounds of interest to prebiotic chemistry;
- Map the distribution of important constituents on the surface; and
- Characterize the radiation environment in order to reduce the uncertainty for future missions, especially landers.

2.1.3 Measurement Objectives

The Europa Orbiter Science Definition Team recommended the following measurement objectives in order to achieve the Group 1 objectives using its strawman payload and reference, high-inclination orbit. NASA intends for these measurement objectives to serve only as potentially useful information based on Science Definition Team studies with respect to meeting Group 1 objectives. Other techniques for achieving the Group 1 objectives may be proposed for which these measurement objectives may not be directly applicable. Such an alternative set of measurements could be made using different instrumentation than the strawman payload described below in Section 2.1.4. Proposers should decide for themselves what is needed to meet the Group 1 science objectives in terms of the types of measurements and their accuracies, resolutions, etc., and justify their choices as part of their proposal.

2.1.3.1 Gravity

Europa is distorted by the tide-raising potential of the Jovian gravitational field. Europa's changing shape introduces a periodic term into Europa's gravitational potential. This term is proportional to k_2, the gravitational Love number. The tides cause changes of ~1% in the second-degree harmonic gravity coefficients J_2, C_{22}, and S_{22}. Doppler radio tracking of the spacecraft will allow these gravitational terms to be determined, thereby determining k_2 as well. A completely solid ice layer has k_2 ~0.02, while a liquid ocean overlain by 25 km of ice has k_2 ~0.28. The measurement objective of the gravity investigation is to determine Europa's k_2 Love number to an accuracy of ±0.001. An accuracy of ±0.03 would be sufficient to infer the presence of a subsurface ocean.

In order to measure the second-degree harmonic gravity coefficients to sufficient accuracy, radiometric tracking data would be needed from an orbit altitude between 100 and 300 km with an inclination >70° and eccentricity <0.1. Two different orbital altitudes would be needed during the mission preferably with their orbital planes separated by >10° of precession. Non-gravitational trajectory disturbances must be minimized. Two-way X-band Doppler tracking to an accuracy of 0.1 mm/sec (1 σ with one-minute compression) over a cumulative total of at least three Europa days should be sufficient. Some tracking should be from the higher or slightly eccentric orbit (~300 km apoapsis), and the rest from an altitude of 200 km or less. Tracking arcs should be as long as possible without any spacecraft-induced trajectory disturbances.

2.1.3.2 Altimetry

The height of the tidal bulge on Europa is proportional to the h_2 Love number, which in turn depends on the density and elasticity of Europa. The tidal bulge height is thought to vary as Europa travels in synchronous rotation along its orbit because of its slight orbital eccentricity (e~0.01). At perijove, the bulge's height reaches a maximum, H_{max}, equal to 24 h_2 meters. For a solid ice shell, h_2~0.04 and H_{max}~1 m; for a global ocean lying beneath an ice shell tens of kilometers thick, h_2~1.2 to 1.3 and H_{max}~30 m. By measuring the height of the tidal bulge throughout Europa's orbit, the magnitude and phase of h_2 could be determined. The objective would be to measure h_2 to ±0.04 or better.

In order to measure the tidal bulge with sufficient accuracy, a high-inclination, near-circular orbit at an altitude of <200 km would be needed to provide repeated high-resolution, near-nadir altitude measurements over the regions of maximum tidal deformation. The orbital radius would need to be reconstructed to ~1-m accuracy. This level of orbit determination would need periodic X-band Doppler tracking over a substantial fraction of the orbital mission. Ranging data to an accuracy of ~1 m (1 σ) can also be made available as desired, although having ranging turned on will reduce the downlink data rate capability.

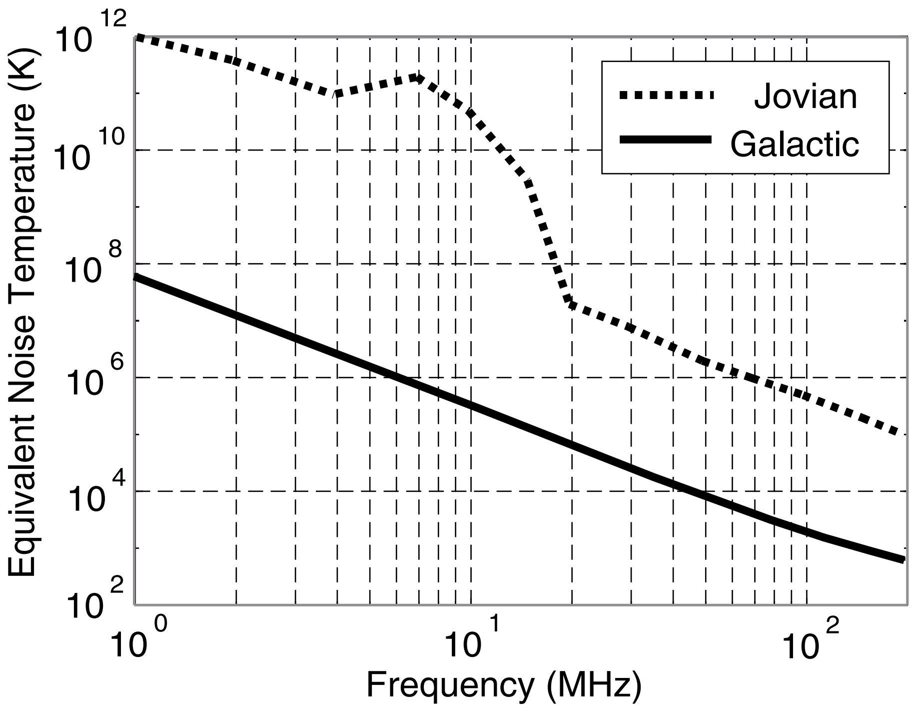

Figure 1. The Europa radio frequency noise environment (S. Gulkis, personal communication).

2.1.3.3 Ice Structure/Interface

The objective of a proposed radar sounding experiment is to investigate the structure of the upper layers of the ice and to search for a possible ice/liquid interface. The probability of making such a detection is maximized by sounding along ground tracks globally distributed in latitude and longitude. The spatial resolution should be at the scale of the major surface features, i.e., ~10 km. The objective would be to achieve a depth resolution of ~100 m near the surface and 10% of the depth at depth. The proposed radar sounding models and the strawman radar hardware description presented here were developed by the Europa Radar Sounder Instrument Definition Team. The Team's complete report can be accessed through Internet URL http;//www.jpl.nasa.gov/ice_fire/SP_SDT_Report.htm.

The thickness of ice that can be sounded on Europa is determined by the absorption of electromagnetic waves in the ice (which is dictated by the temperature and impurity content) and scattering characteristics of the ice body (including the surface and basal interfaces as well as any volume scatterers). Because of the variety of surface terrain types observed on Europa and geologic processes inferred to be at work, Europa's absorption and scattering properties are expected to be spatially inhomogeneous and its crustal ice thickness to be locally variable.

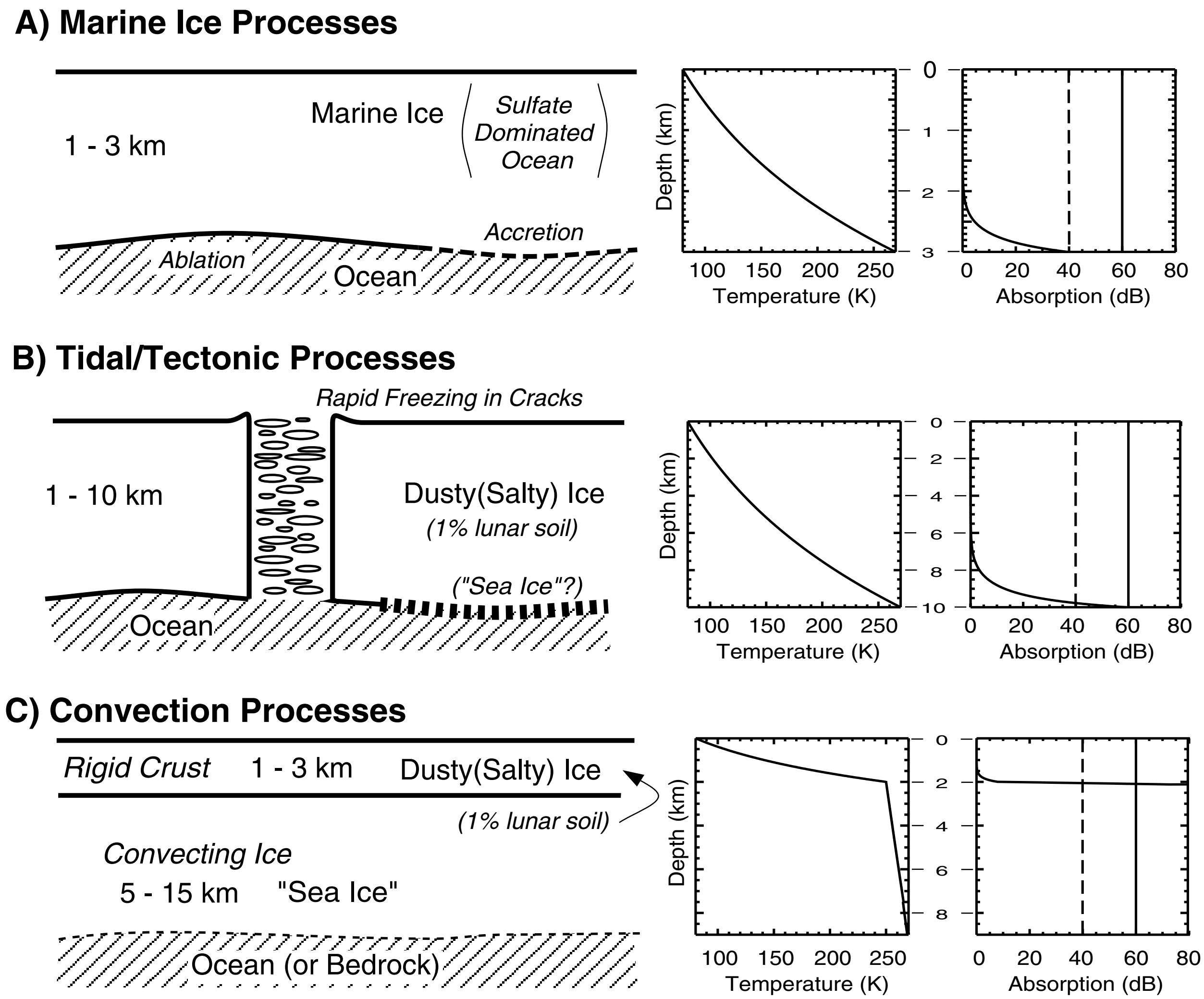

Figure 2. Schematic diagrams of three ice formation processes that may occur on Europa with expected temperature and radar absorption versus depth for each assuming a "mid-latitude" surface temperature of 80K. The range of ice thickness for the models is taken from a summary by Pappalardo et al. (submitted), and the properties of the component ices and ocean are given in Table 1. *A* is a model of ice formation similar to that for marine ice on Earth (e.g., Europa's chaotic terraines) with parts of the base subject to melting (ablation) and others to slow freezing (accretion) of frazil ice crystals; *B* indicates ice formation via extrusion into cracks or fissures with rapid freezing (e.g., Europa's ridged plains); *C* gives a convection scenario with a cold rigid crust underlain by thicker isothermal convecting ice. The dashed vertical line on the absorption versus depth plots for these models indicates the approximate dynamic range of the proposed radar sounder (Figure 3) given the levels of sub-jovian radio frequency noise at 50 MHz (Figure 1); the dynamic range corresponding to the galactic background noise (Figure 1) expected to limit radar sounding on anti-jovian Europa is given by the solid vertical line. Note that for both the "marine ice" (*A*) and "tidal/tectonic" (*B*) examples, a reasonably smooth ice/ocean interface with properties derived from the non-sea-ice entries of Table 1 (i.e., a reflection coefficient of about -3db) can be well characterized.

Figure 2 (cont.). In addition, the reduced reflection strength from dusty-ice (salty-ice) / sea-ice interfaces (e.g., a reflection coefficient of about –20dB) should still allow the base of the rigid crust for the convection model (***C***) to be detected and characterized. A final important result is that the negligible absorption for the upper 80% of the non-isothermal ice for all three models could allow even very weakly reflecting geophysical interfaces to be imaged.

The scattering properties of any assumed sounding model for Europa, as well as the Jovian radio noise environment (Figure 1), are frequency dependent. Earth-based radar sounding of Europa at 3.5- and 13-cm wavelengths suggests that Europa's ice crust contains many high-order multiple scattering inhomogeneities in its uppermost few meters at decimeter scales, which prohibits probing of the ice to any great depth at these wavelengths. However, sounding at 70 cm indicates that scattering inhomogeneities at that wavelength are far fewer. Therefore, radar sounding could be viable at wavelengths of a few meters.

The absorption of radar waves in ice formed by the processes outlined in Figure 2 is dependent on the ice temperature as well as the nature and concentration of any impurities. Table 1 presents the absorption at radar sounding frequencies for a range of ices consistent with the Europan ice formation processes presented in Figure 2. Given the potential ice formation processes of Figure 2, Table 1 presents the calculated radar absorption averaged over the total ice thickness for a range of possible Europan ice; in addition, Figure 2 presents the calculated temperature and absorption as a function of depth ($T(z)$ and $\alpha(z)$, respectively) for these ice formation processes. The strong temperature dependence of electrical conductivity in ice dictates that the temperature profile in the Europan ice layer is a major factor in total radar absorption. Chyba et al., (1998) pay particular attention to the temperature profile for the thermal conducting layer cases (i.e., "marine" ice and tidal/tectonic processes as well as the rigid shell of the convection processes). For a simple conducting ice layer

$$T(z) = T_s \exp(z/b)$$

where the surface temperature is T_s at $z = 0$ and $b = h / \ln(T_b/T_s)$, where h is the ice thickness and T_b is the temperature at the ice base; the surface temperatures on Europa range from about 100K at the equator to 50K at the poles. For the marine-ice and tidal/tectonic processes of Figure 2, T_b could be close to 270K for reasonable ice thicknesses.

To characterize the expected radar returns from Europa's surface, the relevant surface inputs to scattering models must be specified. Observed from Earth, the radar return from Europa's surface decreases significantly as the wavelength increases (Ostro et al., 1992; Ostro, private comm., 1998); this suggests that low-frequency returns from Europa may be due to similar scattering mechanisms as those operating from Earth's icy surfaces. A two-scale scattering model (Tsang, 1985), has been used successfully to characterize radar returns from a variety of rough surfaces on Earth. The best available data for the large-scale surface characteristics are obtained by using stereo-derived DEM (digital elevation models) obtained by using Galileo imagery. An examination of the slope probability density function (pdf) shows that

Table 1: Radar absorption for various ice types and temperatures. Absorption, α, is in dB/m at 251 K. Columns I and II are computed two-way averaged absorption over the total ice thickness, in dB/km, for ice shells with base temperatures of 270 and 250 K, respectively. These values are independent of shell thickness since the temperature profile is stretched to the ice thickness. The range of values for each Column I or II entry corresponds to surface temperatures of 50 and 100 K. The shaded rows of the table represent less realistic ice types for Europa. The distribution coefficient affecting the marine ice models comes from Ronne Ice Shelf marine ice measurements. Note that the absorption losses for the dusty (salty) ice models are calculated using pure-ice behavior consistent with the existing Table 1 entry, which leads to small differences from the losses given in Chyba et al., (1998).

Ice Type	Impurity Content	α (dB m^{-1})	I (dB km^{-1})	II (dB km^{-1})	Notes
Pure Ice	Nil	0.0045	1.4 - 2.4	0.2 – 0.3	Glen and Paren (1975)
Marine Ice (Chloride dominated Europa ocean)	3.5 ppt chlorinity ocean	0.016	4 - 7	1.6 – 2.8	Scaled from Earth ocean, $k_{MI} = 7x10^{-4}$
Dusty (Salty) Ice	1% lunar soil (or salt)	0.008	5 – 6	3.6 – 4.1	Chyba et al., (1998) recalculated
Dusty (Salty) Ice	10% lunar soil (or salt)	0.01	8 – 9	6 – 7	Chyba et al., (1998) recalculated
Marine Ice (Sulfate dominated Europa ocean)	10 ppt chlorinity ocean	0.037	9 - 16	4 – 7	Kargel, (1991); $k_{MI} = 7x10^{-4}$
Dusty (Salty) Ice	50% lunar soil (or salt)	0.021	30 - 33	28 – 31	Chyba et al., (1998) recalculated
Marine Ice (Ronne Ice Shelf)	0.025 ppt chlorinity ice(≈ 35 ppt chlorinity ocean)	0.15	36 - 61	18 - 31	Moore et al.,(1994)
Sea Ice (Baltic Sea)	≈ 3 ppt chlorinity ocean	0.85 (at 270K)	50 - 85	16 - 27	200 MHz radar measurement

the distribution of slopes is generically characterized by unimodal distributions with large tails, which are not well fit by Gaussian distributions. The tails of the distributions exhibit slopes that could be greater than some angle of repose.

The specular, or geometric optics, return can be shown to be proportional to the product of the Fresnel reflection coefficient times the pdf of surface slopes. Using the slope pdf for the Pwyll region, the predicted geometrical optics contribution decreases linearly in dB space from about -10 dB to -20 dB as the incidence angle varies from 0° to about 20°. A conservative estimate of the geometric optics contribution is to assume that very few surface glints are obtained for surface slopes greater than the angle of repose. This produces a geometric cross section that decreases rapidly for incidence angles greater than 30°. Since the geometric cross section merely reflects surface glints, it is nearly frequency independent. It can be assumed that the small-scale surface exhibits the same spectral decay as the measured large-scale surface, and that the small-scale RMS surface height varies between 1 to 10 m.

Summarizing the surface scattering results for the Europan radar sounding model, it can be expected that for incidence angles smaller than 30°, the total cross section is dominated by the geometric optics return (-10dB to -20 dB), which is frequency independent. For incidence angles greater than 30°, the cross section can vary between -40 dB to -20 dB depending on the surface characteristics present. This result is attributable to the rugged nature of Europa's terrain and the large slopes that can be encountered for some of its unusual features as well as difficulties in assessing the presence of slopes greater than the angle of repose. Figure 3 shows the strength of the surface-scattered return (given the radar sounder hardware/processing implementation of Sec. 2.1.4.3). For this figure, the two-scale scattering model of Europa's surface contrasted with a cosine squared scattering function extrapolated from the known scattering of Europa at microwave wavelengths and assuming –10 dB near-nadir losses.

Models of the scattering from any Europan ice/ocean interface are problematic because the geometry of any presumed interface is uncertain. In the absence of significant height variations in the ice-water interface and given the preferred ice and ocean properties of Table 1, the coherent contribution from this interface is at most a few dB of reflection loss. The attenuation of the coherent return will be greater at higher frequencies for the case of significant height variations at this interface. For this reason, the Instrument Definition Team proposed a sounding frequency of 50 MHz as the best trade-off between increasing Jovian radio frequency noise (with decreasing frequency) and increased scattering from any ice/ocean interface (with increasing frequency). Assuming scattering from a Europan ice/ocean interface that is the same as that for the ice surface, Figure 3 shows the expected strength of the return from this interface (as a function of total ice thickness) for the 50-MHz radar sounder described in Sec. 2.1.4.3.

Figure 2 shows the calculated two-way absorption versus depth for the three proposed ice formation processes on Europa, and Figure 3 shows the modeled strength of the return from an ice/ocean interface for these processes. For both the marine ice and tidal/tectonic processes

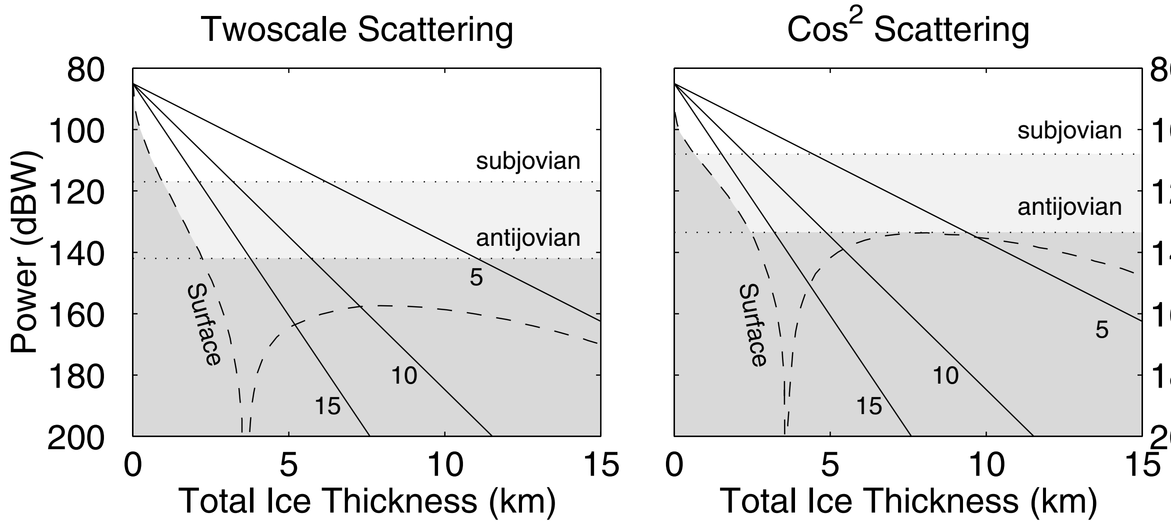

Figure 3. System performance for the proposed 50-MHz Europa radar sounder in the context of two possible scattering models for Europa's surface (dashed lines). The sub-jovian and anti-jovian radio frequency noise limits (dotted lines) are derived from Figure 1 and modified by the processing algorithm appropriate for the surface scattering model. The strength of the return from an ice/ocean interface (assuming the same scattering model as for the surface) over a probable range of Europa ice formation models is presented as solid lines: the line labeled 15 shows the expected return as a function of total ice thickness for the marine-ice model of Figure 2 at equatorial temperatures (see the marine-ice entry for a sulfate-dominated Europa ocean in Table 1, i.e., -15dBW km^{-1}); the line labeled 5 shows the expected return again as a function of total ice thickness for an ice/ocean interface given the tidal/tectonic ice formation processes of Figure 2 at polar temperatures (see the dusty (salty) ice entry for 1% lunar soil in Table 1, i.e., -5 dBW km^{-1}); the solid line labeled 10 again corresponds to the expected return as a function of total ice thickness for tidal/tectonic processes but at equatorial temperatures and for the dusty (salty) ice entry with 10% lunar soil in Table 1, i.e., -10 dBW km^{-1}. The darkest gray shading indicates the noise floor for radar sounding on anti-jovian Europa while the lighter gray shows the much higher noise floor for sub-jovian radar sounding. Experience with terrestrial radar sounding of ice sheets indicates that laterally continuous returns with a strength equal to the noise floor are routinely detected in radar sounding images.

(i.e., T_b=270K), the ability to characterize any ice/ocean interface or internal layering could be inferred directly from these plots. Recalling that a smooth ice/ocean interface would give negligible reflection losses, Figure 2 shows that the total absorption is less than the expected instrumental dynamic range over the full range of total ice thicknesses expected for both marine and tidal/tectonic ice formation processes on anti-jovian Europa. This is also the case for the rougher ice/ocean interface assumed in Figure 3. In addition, Figure 3 shows that the range of total ice thickness soundable on sub-jovian Europa is reduced by about one-third (to a little over 2 km for marine ice and 6 km for tidal/tectonic ice formation processes) compared with anti-jovian sounding.

For the "convection" processes of Figure 2, the deeper warm layer may be likely to contain brine pockets, as the ice temperature could be above the eutectic point of some chloride salts.

Because of this, absorption would become very high (similar to the sea ice of the Baltic Sea or even higher; Table 1), and radar could be unable to penetrate the ice to any subsurface ocean. If the boundary is reasonably sharp, there would be a radar reflection from it due to the change in dielectric impedance. The magnitude of the reflection would depend on the brine content in the ice and its spatial distribution. A relevant example is the reflection coefficient observed at the boundary between cold-dry and temperate-wet glacier ice with an essentially uniform distribution of water pockets, which is typically about –20 dB (Bamber, 1987). Assuming a similar reflection coefficient for convection processes on Europa, Figure 2 shows that it is very likely that radar would penetrate the full range of expected rigid lid thicknesses and allow characterization of the interface with the convecting layer beneath. Figure 2 also shows that any icy crust formed by a tidal/tectonic process dominated by ocean water injection and rapid freezing could also be characterized by "sea-ice"-like absorption at depths where temperatures are above the eutectic point of any constituent chloride salts. If this were the case, it would only be the upper surface of this sea-ice layer that could be characterized.

The proposed radar sounder implementation, described in Sec. 2.1.4.3, should sample globally the major surface features of Europa to expected depths of up to 10 km (or even 20 km for very clean, non-convecting ice). These soundings would have a spatial resolution of one to two km (for orbit elevations of 100 to 200 km) and a depth resolution of ~100 m.

2.1.3.4 Imaging

To meet Group 1 objectives, the measurement objective would be to attain global mapping in at least two colors at <300 m/pixel resolution. In addition, it is an objective to sample representative feature types on the surface at 3 - 30 m/pixel resolution in a single color. Measurement objectives include having a wavelength capability out to at least 1 μm in order to discriminate known color/stratigraphic relationships.

2.1.3.5 Pre-Europa Orbit Measurements

Once in Jupiter orbit, numerous opportunities may arise for useful scientific observations of Europa and possibly other parts of the Jovian system, both for instrument checkout and calibration and for additional scientific return. The Project plans to begin limited science operations following JOI, the scope of which will be determined when more detailed mission plans are developed following selection of investigations. Pre-Europa Orbit phase science planning will be constrained by a number of factors and will be considered under the following guidelines:

- The mission design will be driven by the requirement to minimize the delta-V, absorbed radiation dose, and duration of the Tour/Endgame in support of the Europa Orbit mission objectives, not by Tour or End Game science opportunities.
- Spacecraft and ground system requirements and resources will give priority to Europa Orbit phase requirements.

- Essential instrument checkout and calibration will be given priority over other science activities.
- Science observations which directly address or enhance the primary Europa Orbiter mission objectives will be given priority over other Jupiter system observations.
- Technical constraints including (but not limited to) propellant, communications, navigation, and use of flash memories may also severely limit the Project's ability to accommodate pre-Europa orbit observations.

Proposals should address the minimum required pre-Europa Orbit science checkout and calibration requirements. Because the scientific return from the pre-Europa orbit period cannot be guaranteed, it would be prudent for investigators to base their ability to meet the Group 1 science objectives only on the period of time that the mission is in orbit around Europa.

2.1.4 Strawman Payload

The following strawman list is an illustrative science payload used as the basis of the Science Definition Team's measurement objectives for the Europa Orbiter mission. Of course, none of the instruments in this illustrative set has been selected (with the single exception of the spacecraft transponder), and alternative and better approaches to meeting the Group 1 objectives may well exist. Novel concepts that can meet the Group 1 objectives are encouraged. The proposed facility radar sounder is described in more detail so that interested scientists may propose to use the radar, in case it is selected as part of the payload.

2.1.4.1 Radio Science

The spacecraft transponder, which will serve as the basis of the Doppler tracking gravity measurement experiment, is a facility instrument provided by the project. The combined spacecraft telecommunications subsystem and DSN ground stations links can provide two-way X-band Doppler tracking to an accuracy of 0.1 mm/sec (1σ) with 30 seconds of integration time per data point.

2.1.4.2 Laser Altimeter

The strawman laser altimeter reviewed by the Science Definition Team is based conceptually on characteristics of flight laser altimeters flown on Clementine and Mars Global Surveyor. A system of this general type was judged capable of meeting the recommended measurement requirement, given accurate orbit determination. Adapted for Europa conditions, the strawman system has a mass of 5.1 kg (including an estimated 2 kg of radiation shielding), average power of 7 W (15 W peak), and has a transmitted beam with 0.5-mrad divergence (~100-m IFOV at 200 km altitude). The main optical elements consist of a 5-cm aperture receiver boresighted with the laser transmitter. The transmitter has a volume of 20x8x8 cm, and the receiver 15x10x10. It is noted that in some designs the receiver might share optical elements with other remote sensing units such as an imaging system, possibly resulting in mass savings, but the strawman design does not assume this. A raw data rate of 2 kbps and a compressed rate into storage of 400 bps were assumed. Data volume for a two-orbit cycle would be 3.3 Mb. For a shuttle launch, a cover and purge for contamination control were also assumed.

2.1.4.3 Radar Sounder

If an ice penetrating radar (IPR) system is selected, NASA has decided that it will be developed by the Project through a consortium and operated as a facility instrument for scientific investigations. Investigators may propose in response to the AO to conduct investigations with the IPR in the same way that they would propose to conduct investigations with a facility instrument. Independent IPR instrument designs are not solicited by this AO; nor should an IPR be included in an integrated payload proposal.

The proposed Europa radar sounder concept hardware consists of a Yagi antenna, 20-W transmitter, and a sensitive receiver with digital output to the spacecraft computer bus (Figure 4). Data reduction is achieved in the radar hardware by employing a sensitivity time control (STC) to reduce the echo dynamic range and a "deramp" mixer to reduce the signal bandwidth necessary for processing. Further data reduction is performed in the processor by azimuth compression and echo averaging. The primary operating frequency for the radar system is 50 MHz, which corresponds to a 6-m wavelength in a vacuum and ~3.5 m in ice.

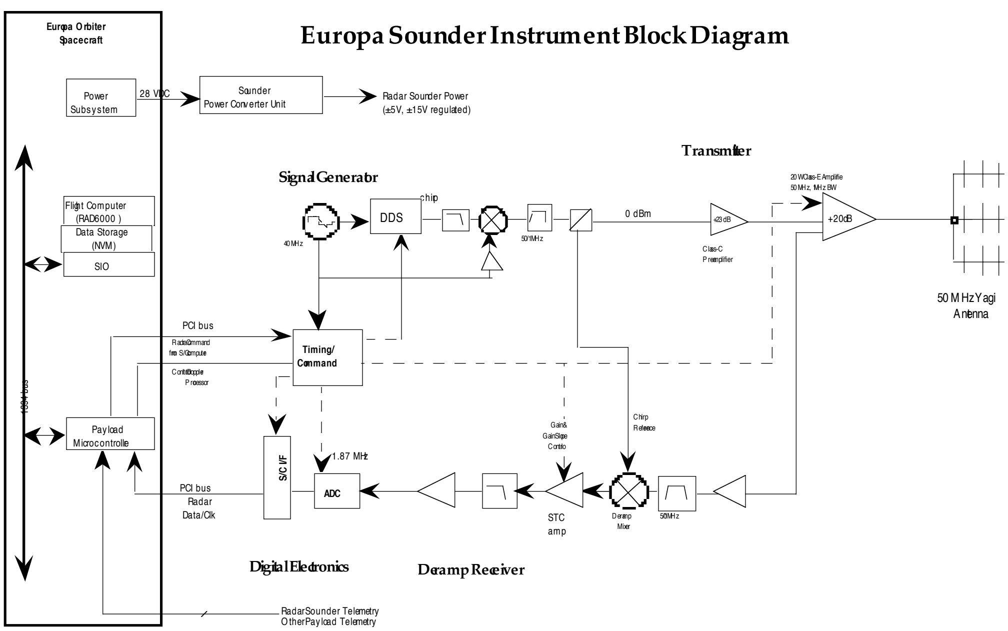

Figure 4. Block diagram of proposed Europa radar sounder.

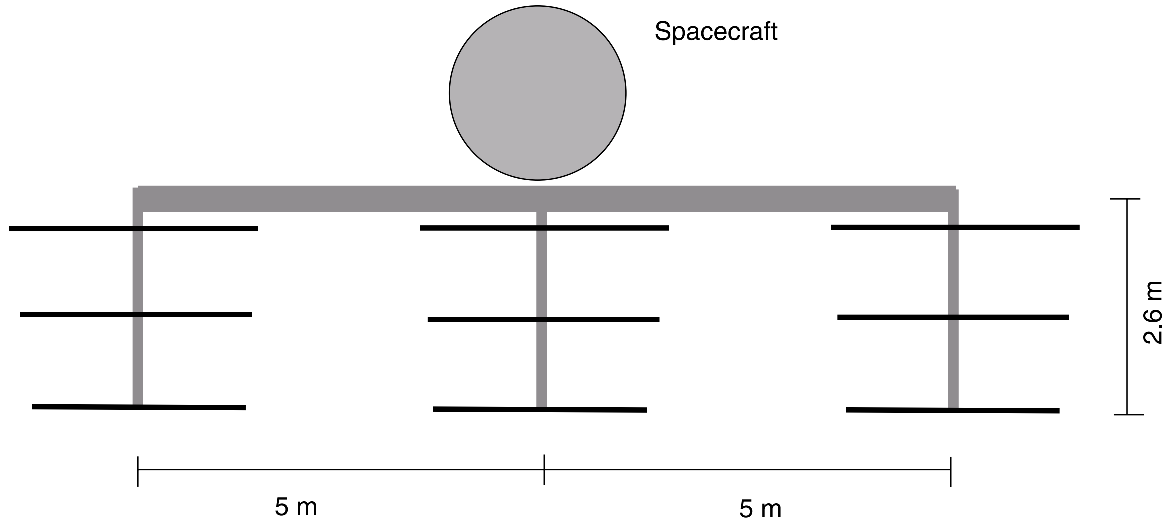

Figure 5. Fully deployed antenna structure. The thin solid lines in the figure represent the antenna elements; and the gray bars represent the supporting booms. The array will be pointed toward Europa with its baseline-oriented perpendicular to the track of the spacecraft.

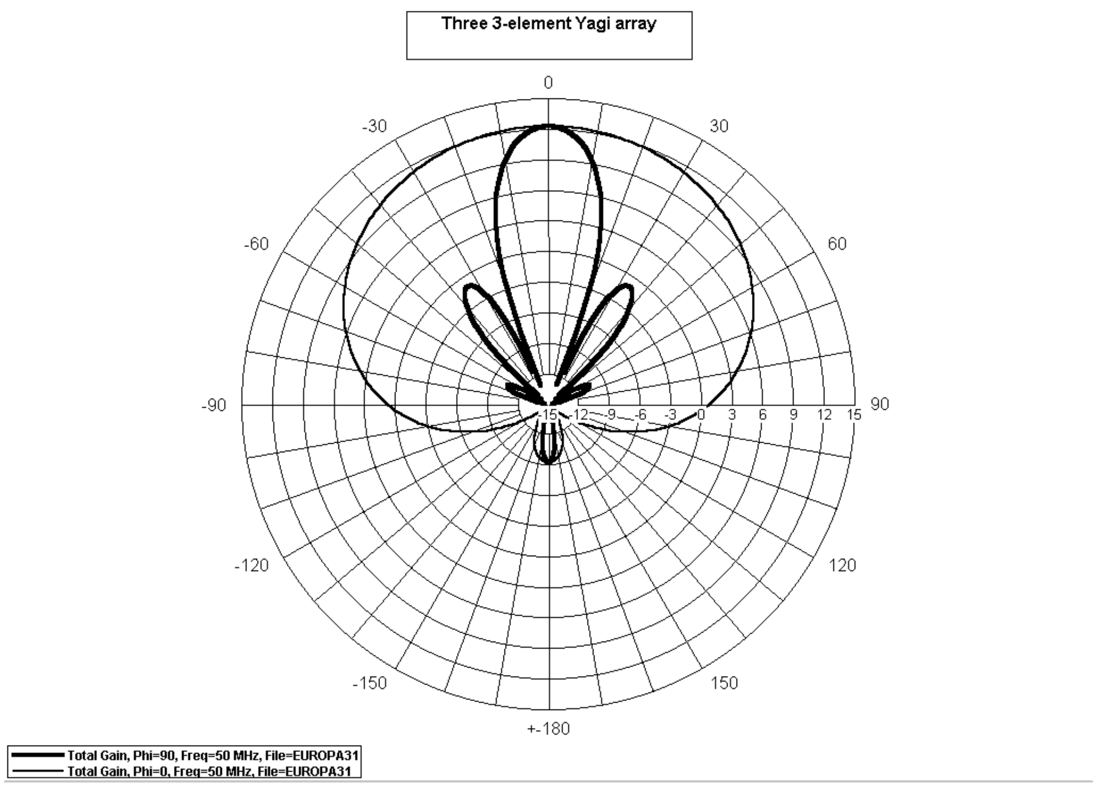

Figure 6. Simulated one-way antenna patterns in the cross- and along-track directions. The 3-dB beamwidth is about 20^o in the cross-track direction, and about 100^o in the along-track direction.

An array of three standard 3-element Yagi antennas is proposed for this system (Figure 5). This antenna array will form a relatively narrow beam pattern. The array will be pointed toward Europa with its baseline-oriented perpendicular to the track of the spacecraft.

Figure 6 shows numerical simulations of the 50-MHz antenna pattern in the cross- and along-track planes. The array has a maximum gain of approximately 12 dB in the nadir direction with 3-dB beamwidths of about 20° and 100° in the cross- and along-track directions. The first side lobes in the cross-track direction are roughly 37° away from the nadir direction and are about 13 dB down in the gain level. Since the antenna array will be used for both transmitting and receiving, the side lobe levels will be 26 dB below the main lobe. The front-to-back ratio is about 20 dB at 50 MHz.

The radar transmits a linear-FM (chirp) waveform using direct digital synthesis (DDS) technology, where a numerically controlled oscillator (NCO) is used to derive the frequency modulated sine-wave output. The high dynamic range requirement results in the need for dynamic gain control. The deramp design uses the transmit chirp waveform to downconvert the chirp rather than using a conventional LO signal. This deramp technique will reduce the system data rate by performing analog chirp compression. An STC (variable gain amplifier) is used to reduce the dynamic range requirement by weighting the deramped chirp as a function of time or frequency.

The digital system consists of a 12-bit analog to digital converter with a timing and control circuit and PCI interface. The spacecraft processor starts the radar data collection and processes the radar data after it has been written to the spacecraft processor memory. The pulse repetition frequency (PRF) signal generated by the timing and control circuit triggers the transmit. The return echo is fed into the ADC. At the proper time during the pulse return, the timing and control circuit will create a data sampling window, during which the ADC will sample the video signal and convert it to parallel 12-bit digital words. The sampling clock rate is set to approximately 2.2 times the bandwidth or 1.87 MHz. The ADC will sample approximately 25% of the echo return period resulting in an average data rate of approximately 6 Mbps to the spacecraft processor. The spacecraft processor can then perform real-time processing on the radar data.

Table 2 summarizes the system parameters for the anticipated Europa radar sounder.

Representative science data output capabilities of the Proposed Europa Radar Sounder are as follows. The baseline mode is expected to return to Earth all data collected by the sounder, processed onboard into waveforms having depth and along-track resolutions equal to the radar's capabilities. A second mode offers waveforms averaged in depth resolution or in along-track spatial resolution, either version having a lower data rate than the baseline mode. The purpose of this mode is to allow survey radar sounding to co-exist with other Europa observations such as geodesy, or to adapt to any other data rate or data volume constraint. Finally, a third mode supports the digitized radar sounder complex data, prior to onboard

Table 2. Proposed Europa Sounder system parameters.

Parameter	
Transmit Power[1]	20 W
Antenna Gain	12 dB
Pulsewidth[1]	500 μsec
PRF	375 Hz
Bandwidth	0.85 MHz
Receiver Dynamic Range w/ STC	90 dB
A/D quantization	12-bits/sample

[1]Other combinations may be considered to mitigate potential side lobe problems.

waveform processing, captured on a per-pulse basis. This mode, whose data rate and volume would far exceed routine operating capabilities of the sounder telemetry, requires onboard buffer storage prior to downlink at a slower rate. Data in this mode may be useful for initial validation of the sounder's performance and for specialized (and relatively rare) observations of selected regions of Europa.

"Waveform" in this discussion is meant to imply a mapping of signal strength as a function of delay time, which in turn is proportional to depth of penetration of the radar's emitted energy into the ice. Once the waveforms are returned to Earth, sequences of them may be combined to form profiles of ice penetration along the sub-satellite tracks. Each waveform is the product of processing the observed echoes of several thousand individual pulses transmitted by the radar. The proposed radar sounder and its onboard processing would be designed to: (1) resolve the along-track footprint size of each waveform to be as small as possible (typically < 2 km), (2) resolve the depth measurements of scattering layers and potential ice/water interfaces (typically ~ 100 m), (3) measure the mean altimetric elevation and large-scale roughness of the surface of the ice (estimated accuracies for which are ~15 m and ~30 m, respectively), and (4) estimate the radiometric properties of reflection and losses within the ice. Spatial (along-track) resolution is taken in this context to mean the size of each individual waveform's footprint after onboard (Doppler) processing, and depth resolution implies the size of each depth data bin.

The science waveforms to be produced by the proposed Europa Sounder may differ from those described in these paragraphs. Implementation details of processing and waveform generation will be determined by the final design of the sounder. The actual waveform telemetry formats will take into account preferences and/or requirements of the science community, subject to constraints that may be imposed by the radar design, onboard processing resources, and the capacity of the data downlink.

The proposed radar sounder, even at the relatively low pulse repetition frequency (PRF) of about 400 Hz suitable for the 50-MHz band when operating from 100 km above the surface, would be turning out approximately 100 times more data than the mission telemetry can accommodate continuously in real time. Onboard processing is essential to reduce the data volume to a manageable size.

The notional onboard processor strategy, outlined below, is a blend of conventional coherent and incoherent integration (known as "stacking" in the sounding community) augmented by similar integrations implemented in parallel data paths. Conventional coherent integration selects only those sounding data whose Doppler frequencies (i.e., the change in frequency due to the relative motion between the sounder and the sounding target) are at or near zero. The extra data paths arise at offset Doppler frequencies (i.e., the frequency change due to the relative motion of the off-nadir targets). The improvement in sounder performance is directly proportional to the number of such parallel Doppler paths incorporated into the processors. The end result of the waveform processing is a single sounding waveform at each resolved along-track position (Raney, 1998).

The transformation of the pulse-to-pulse radar echo data into waveforms suitable for downlink telemetry to Earth is outlined in Figure 7. Following dynamic range compression and analog-to-digital conversion, the average rate of the raw data from the radar sounder is approximately 6 Mbps. These data are captured in the working memory of the coherent Doppler integrator. Subsequent steps operate on blocks of 64 input range lines at a time to generate coherent migration-corrected sounding waveforms in N parallel Doppler bins, (where 1<N<~25, subject to processing limitations). These coherent waveforms are detected, registered along-track, and summed, all in the incoherent waveform integrator. The resulting waveforms represent the full-resolution sounding measurement capability of the radar. The telemetry format processor serves as the interface between the full-resolution waveforms and the data downlink system, matching the data delivered to the telemetry system to its mode requirements.

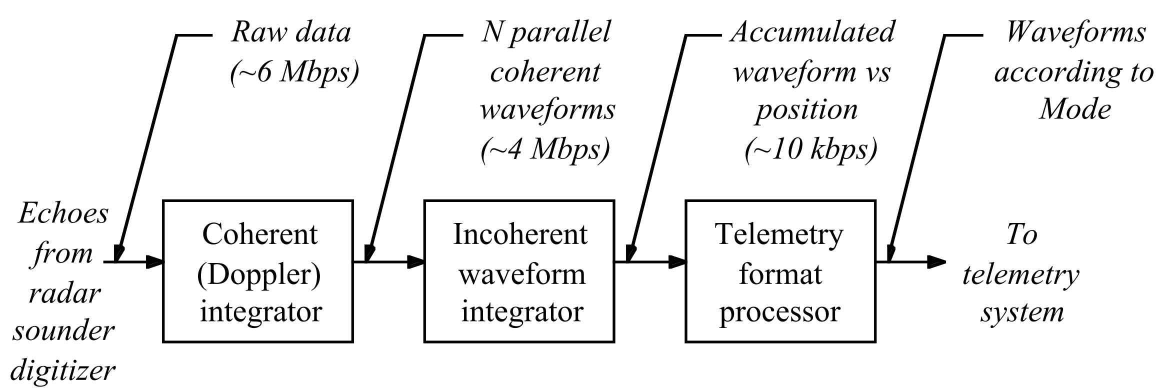

Figure 7. Concept of data flow from the proposed radar sounder to the telemetry system

The proposed nominal baseline radar sounding mode, denoted here as Mode 1, fits within the mission budget for data volume and data rate. The average Mode 1 data rate of 6.5 kbps is sufficient for continuous telemetry of the full resolution waveforms and also is low enough that the data volume required by a full set of surface soundings is substantially less than 10% of the mission budget. On the other hand, if there were deeper data rate or volume constraints, then the sounder output data rate would have to be reduced, nominally to 1 kbps, average. This low rate is designated Mode 2, which may be realized either by averaging waveforms in depth (Mode 2.1) or by averaging waveforms along-track (Mode 2.2).

Alternatively, higher rate data may be collected and stored in a buffer, then subsequently downlinked at a lower rate to the Earth. The internal (complex) data rate from the radar sounder (prior to the waveform processors) is about 6 Mbps average. A reasonable lower limit on the useful amount of such data is about 15 seconds, which would be sufficient to allow the mid-beam portion of the antenna illumination to completely scan a given sub-satellite point. This corresponds to about 90 Mb of data. Several such high-rate snapshots could be gathered without overburdening the onboard data storage or downlink resources.

Mode descriptions (50-MHz data)

Mode 1 and Modes 2 are designed to transmit waveforms at or near the maximum applicable rate given the constraints imposed by current mission operations. In all modes, the approach is to downlink individual waveforms, each one to include a control word. The (real) waveforms would be represented by floating point magnitudes with one digital number per depth bin. The control word would provide: (1) the surface height (which is proportional to the delay time to the first reflection received at the radar), (2) the amplitude scaling factor, (3) the rate of change of the amplitude scaling factor with depth, (4) the radar PRF (which is a function of satellite height, and on which radiometric and geometric scaling depend), (5) spacecraft time (or an equivalent index of the waveform's along-track location), (6) mode flag, and (7) ancillary data. Note that the amplitude scaling factor and its slope are required in response to the very large dynamic range of reflected power expected for the sounding echoes.

In all modes, data would be included that captures received signal strength both before the first surface reflections and deeper than the nominal 20 km. The early returns are valuable because: (1) they provide a sample of the prevailing noise, including additive system and ambient environmental noise; (2) they allow an estimate of the presence of sensible range ambiguities; (3) they support estimation of the mean (large-scale) surface roughness, and (4) they serve as a measure of the fine-scale distance between the radar and the surface, thus allowing the proposed sounder to serve as a radar altimeter.

Mode 1: Full-Resolution Waveforms (FW)

A notional limit of 6.5 kbps would allow 256 depth bins to be encoded at 20 bits floating point together with a control word of about 1.4 kb. Thus, a sequence of waveforms in Mode 1 would support generation by an investigator of a profile consisting of soundings each having several hundred degrees of freedom, depth resolution of 100 m over a full 20-km ice thickness, and spare depth bins to cover early returns prior to the first surface and late returns to flag deeper responses. This is the default standard operating mode for the sounder.

The satellite's orbital height is the primary determinant of the along-track sounding interval, which would be about 1.4 km for a satellite height of 100 km expanding to about 1.9 km from a height of 200 km. The statistical degrees of freedom within each waveform, which are proportional to the number of incoherent integrations available, is to first order a constant over this range of orbital heights. Average data rate decreases with increasing orbit height, since one waveform is produced for each resolved along-track sounding interval.

Europa completes one revolution within about 3.5 days. If the radar sounder were to gather data for 7 days at a 50% duty factor, it could generate a complete set of surface soundings, subject, of course, to the cross-track spacing of adjacent orbits. Such a Mode 1 data set would require less than 2 Gbit.

Mode 2: Averaged Waveforms (AW)

The data rate or volume available to the radar may preclude full resolution sounding for portions of the mission. The averaged waveform modes are chosen to meet this contingency, fitting their science return within a 1 kbps limit. Consider one example. If the radar sounder were to gather data in Mode 2 for 7 days at a 50% duty factor, it could provide a survey of the surface, subject to the reduced resolution implied by averaging. Such a survey in Mode 2 would require only about 300 Mbits total data volume.

Mode 2.1: Averaged Depth Waveforms (AW-D)

> One means of reducing the available data rate for each waveform is to aggregate resolution cells that lie at deeper levels, consistent with the depth resolution requirement: the greater of 100 m or 10% of depth. One means of doing this is described in Table 3. In this mode, waveforms would be downlinked that correspond to full resolution along-track, but which have selective depth averaging applied. The amplitude would be encoded as 16-bit floating-point digital numbers at 55 depth stations, leaving about 120 bits available for the control word from an orbital height of 100 km, expanding to several hundred bits for the control word from 200 km height. With such a small control word, it may be necessary in this mode to link control words across a group of waveforms.

Mode 2.2: Averaged Surface Waveforms (AW-S)

> An alternative means of reducing the available data rate for each individual waveform is to retain full depth resolution, but to aggregate adjacent waveforms along-track, sufficient to meet the governing average data rate of 1 kbps. One means of doing this is to sum several sequential full-resolution waveforms, and to downlink the result at

Table 3. Mode 2.1 depth bin averaging example

Depth interval (km)	Number	@Resolution (m)
Pre-surface	5	170*
0 - 2	20	100
2 – 5	12	250
5 – 9	8	500
9 – 13	4	1000
13 – 19	4	1500
19 - 21	2	2000

*The in-ice design resolution of 100 meters expands to about 170 meters in free space.

reduced dynamic range. In this mode, from an orbital height of 100 km, the averaged surface waveforms would have along-track resolution of about 5.6 km, and they would retain 100 m resolution at all depths. The amplitude would be encoded as 16-bit floating-point digital numbers at 220 depth stations, leaving about 480 bits available for the control word. The corresponding mode from 200 km height would need to average only three waveforms along-track to accomplish virtually the same performance: 5.7 km along-track resolution, 100 km depth resolution, and 16-bit floating-point radiometric resolution, with about 500 bits available for the control word.

Mode 3: Radar Sounder Data Record (RDR)

The average data rate of the proposed radar sounder after the analog-to-digital conversion is on the order of 6 Mbps. As introduced above, these data could be captured directly and placed in memory, there to await an opportunity to downlink the lot at a slower rate. This mode should be regarded as a special case, to be used only when fully justified. Mode 3 can operate in parallel with Mode 1 or with one of the Mode 2 options. Thus, the way is open to record sets of Mode 3 data in parallel with routine surveys. These data could be used as scheduled periodic adjuncts to survey data or could be focused on selected sites for potential enhancements to the science eventually to be derived from the data.

Sampling Strategy

Approximately 10^{10} bits can be telemetered to Earth during the course of Europa Orbiter's nominal mission, and much of this downlink will be devoted to optical imaging and other experiments. Europa can be completely mapped using Mode 1 data collection (i.e., at full resolution) by a radar sounding system with approximately 10^9 bits. This could be achieved in 2.5 weeks of operation with a 25% duty cycle. The ability of the radar to function on the night side of the satellite adds flexibility to its operation and allows mapping to be conducted with the available spacecraft power resources and processing capability.

Two other types of data products in addition to this primary sounding data may be desirable. First, samples of the unprocessed data (i.e., Mode 3) should be acquired to characterize the permittivity of the Europan subsurface as a function of depth and to tune the operation of the instrument early in the mission. Downlink constraints dictate that only a few such samples can be acquired. At a minimum, equatorial and polar regions of Europa should both be studied and efforts made to examine the major geologic terrain types on the satellite such as ridged plains, chaotic terrain and impact structures.

Second, global mapping at reduced resolution (i.e., Mode 2) should be undertaken. Sounding data at one-tenth resolution could be acquired over extended periods and stored on board the spacecraft for later telemetry. The radar could also serve as a coarse altimeter, providing positional information to augment the geodetic experiments. The total data volume generated by these activities amounts to no more than a quarter of the primary full resolution mapping data set, but greatly enhances the scientific return from the investigation.

2.1.4.4 Imaging System

To address the imaging measurement objectives, the Science Definition Team suggested a strawman imaging system consisting of two framing cameras, although it was noted that other design choices such as push- or sweep-broom systems were also viable and might offer design and/or science advantages in some cases. Detectors were assumed to be Charge Injection Devices (CID) for radiation tolerance, but other choices are certainly possible. The optical system consists of a narrow angle camera (NAC) and a wide-angle camera (WAC). Both strawman systems are f/4 with the NAC focal length of 10 cm and the WAC focal length of 0.667 cm. This yields IFOVs of 100 μrad and 1.5 mrad respectively for the assumed CID pixel pitch of 10 μm. Weight and power are estimated as 1.13 kg and 0.1 W (0.3W peak) for the NAC and 1.53 kg and 3.1 W (3.3 W peak) for the WAC, the higher WAC parameters due to the inclusion of a four-position filter wheel in the strawman design. Again, other choices for meeting the spectral measurement objectives may be as good or better. Volume estimates are 15x5x5 cm for the NAC and 4x4x6 cm for the WAC. The data collection strategy assumed a temporary storage buffer and lossless compression at 3:1 (assumed to be done in software in the spacecraft computer, but hardware implementations could be considered), yielding 3.5 Mb/frame for the NAC and 0.87 Mb/frame for the WAC. With the chosen parameters, contiguous color coverage of the sunlit side during a two-orbit cycle would produce 241 Mb in data storage. The optimum trade-offs among spatial resolution, spectral coverage, and spatial coverage in order to meet the high-level science objectives must be addressed by each investigation proposing to address this class of measurement requirement. Protective covers and purge subsystems are included to prevent contamination in the launch vehicle. A 10-W heater is provided for each camera for contamination control purposes during cruise, if power is available. Radiation concerns must be addressed for optical elements as well as for the detectors and electronics.

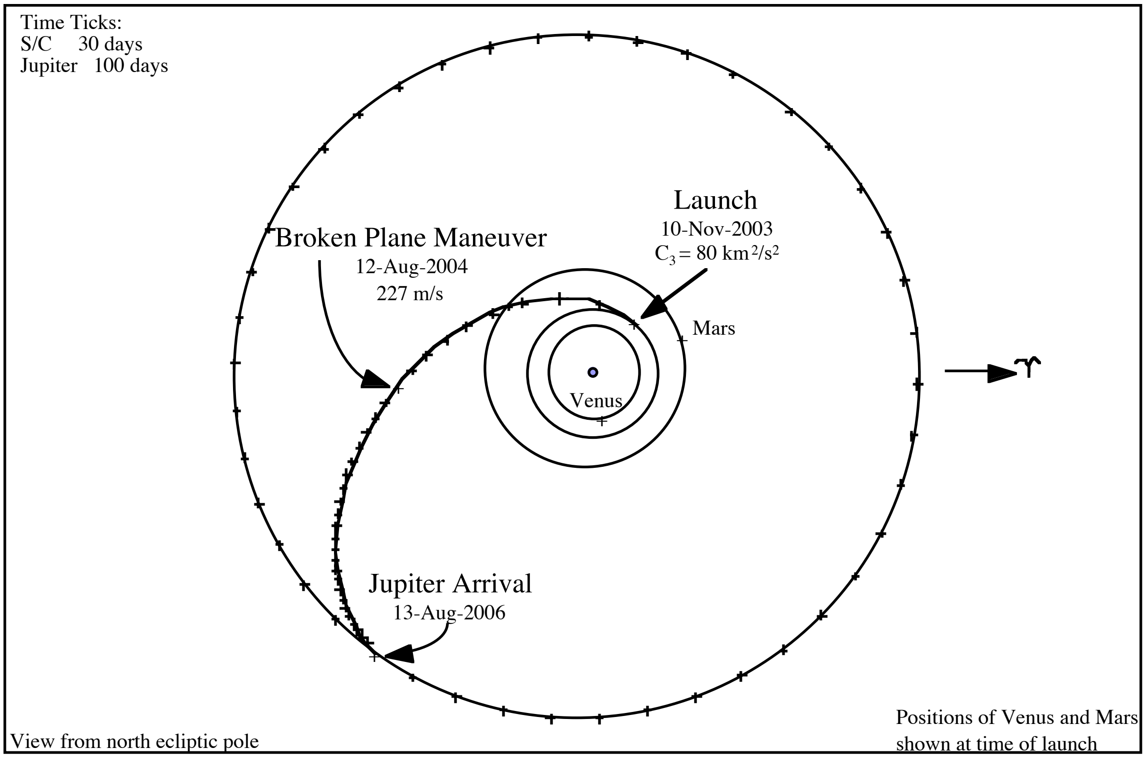

Figure 8. Europa Orbiter 2003 direct trajectory

2.2 Description Of Spacecraft Concept And Mission

2.2.1 Reference Mission

The reference mission and spacecraft concepts described here are for proposal purposes only. Further design work and trade-offs will be completed after science selection.

2.2.1.1 Launch/Interplanetary Trajectory

The Europa Orbiter reference mission calls for an STS/IUS/Star48V launch in November 2003. The spacecraft will take a direct trajectory to Jupiter (see Figure 8), arriving between August 2006 and August 2007 (depending on launch date).

The opportunity to switch the launch order of Pluto/Kuiper Express (PKE) and Europa Orbiter (EO), however, is a key requirement of the program readiness strategy. If the option to switch the order of the PKE and EO launches is exercised, the PKE launch would be moved up to November 2003, and EO would move into the December 2004 slot. Arrival would be proportionately later, of course.

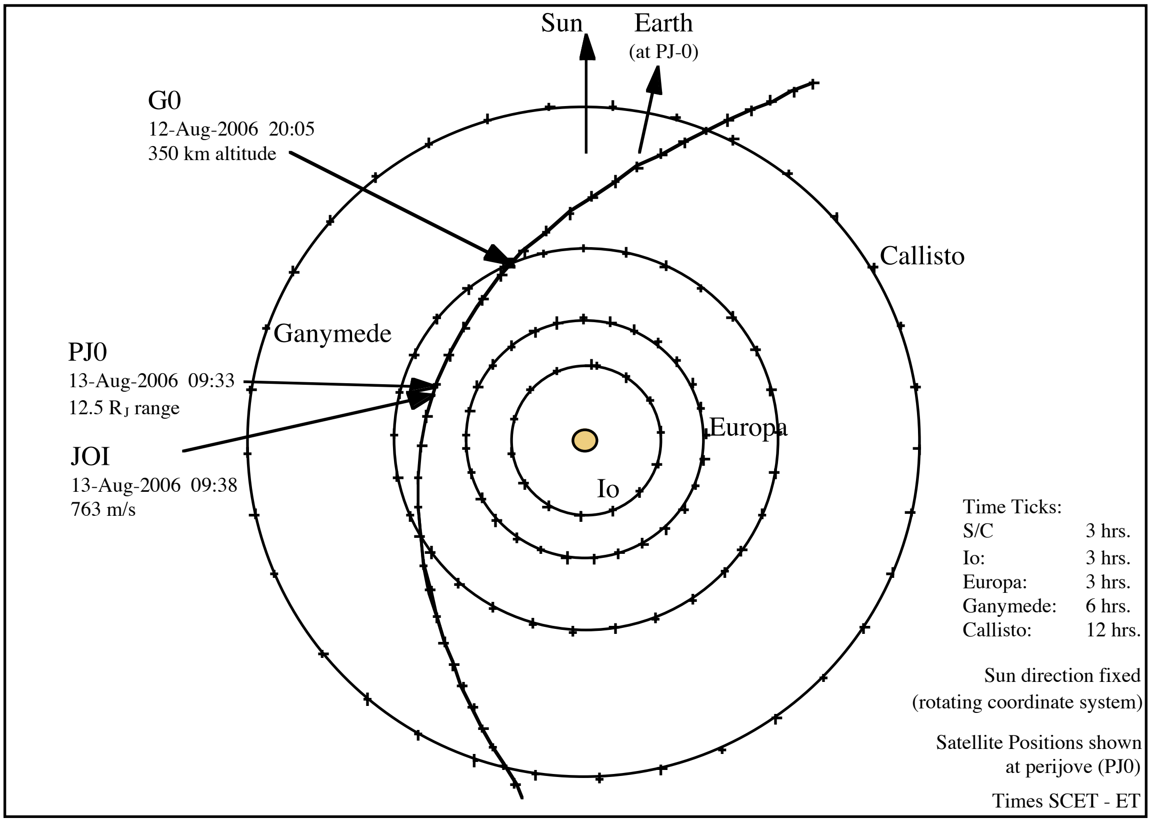

Figure 9. Europa Orbiter - Jupiter arrival geometry.

2.2.1.2 Jupiter Arrival

Upon arrival into the Jupiter system (see Figure 9), EO will get an inbound gravity assist from Ganymede just prior to the Jupiter Orbit Insertion (JOI) burn of up to 1000 m/s. JOI will target the spacecraft for a roughly 200-day initial orbit about Jupiter (see Figure 10), which after a small perijove raise maneuver, will return to Ganymede (G1).

2.2.1.3 Tour/Endgame

A Galileo-like tour of the satellites Europa, Ganymede, and Callisto will begin with G1 (see Figure 11) and is nearly ballistic. It will take at least a year from arrival at Jupiter to get the spacecraft to the beginning of what is called the Endgame, which is the part of the trajectory during which the spacecraft will use only Europa flybys and large propulsive maneuvers to achieve the desired final approach to Europa (see Figure 12). The primary goal of the tour/endgame is to minimize delta-V in reaching a high-inclination orbit about Europa.

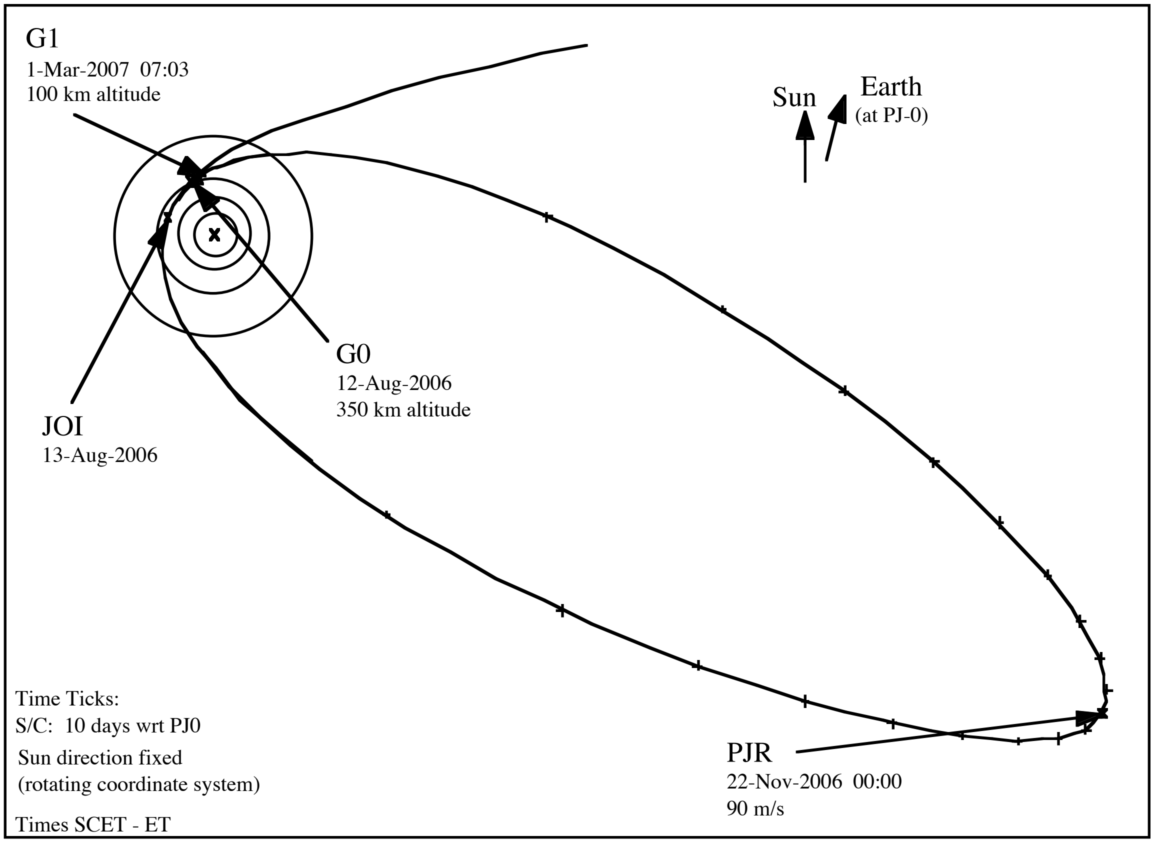

Figure 10. Initial Jupiter orbit

Secondary goals are to keep the total radiation dose to <2 Mrads and the duration from JOI to EOI to <3 years.

The roughly half-dozen Europa flybys that constitute the Endgame may exhibit more or less the same spacecraft/Europa geometry depending on the final Endgame design.. Satellite flyby altitudes are expected to range between 100 and 10,000 km. The Endgame is expected to take about 3 months and culminates in an elliptic approach by the spacecraft to Europa. Preliminary estimates put the total radiation dose for the endgame at about 2 Mrads, half of the mission total of 4 Mrads (behind 100 mils of Al), the other half coming during the 30-day primary mission around Europa.

2.2.1.4 Europa Orbit

A large, >500 m/s burn, will put the spacecraft into a low-eccentricity interim orbit from which the gravity field mapping experiment can begin (the current reference periapsis altitude is 200 km, although the actual value is subject to future analysis/negotiation). The eccentricity of the interim orbit around Europa, and the duration of stay in that orbit, will be

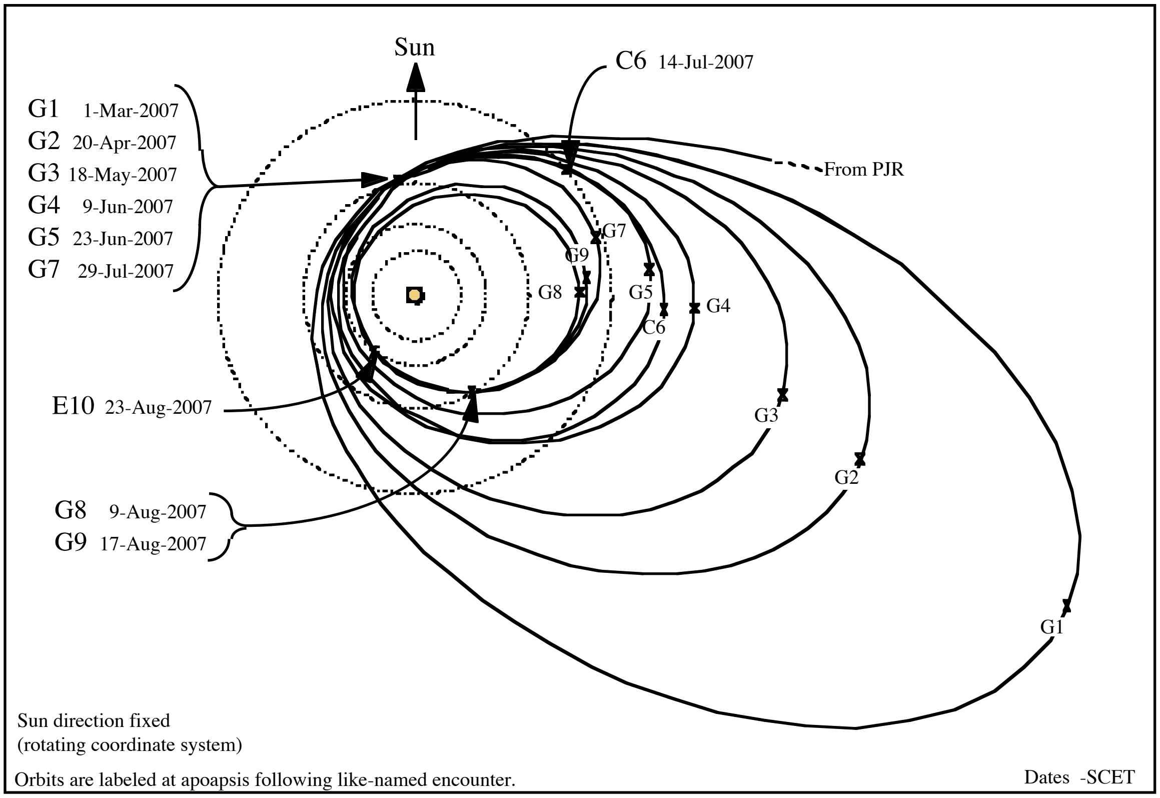

Figure 11. Representative Europa Orbiter satellite tour trajectory

dependent on orbit-stability and gravity-science studies that will be conducted in the Project's development phase. The gravity field mapping requires different orbits to help separate the small atmospheric effects from the gravity field signature and also the higher order gravity harmonics from each other. By "walking down" the initial apoapsis, it is believed that this requirement can be met at no significant additional delta-V cost (in fact, it may reduce finite burn losses of the orbit insertion). There is no specific allocation of delta-V for an altitude change once in close Europa orbit, although 20 m/s is allocated for orbit control over the 30-day mission. This allocation is sufficient to maintain altitude control within a ±10-km range.

Table 4 includes a summary of the range of key parameters describing the final mapping orbit around Europa.

After the appropriate length of stay in the initial eccentric orbit, the spacecraft will circularize its orbit at 100-200 km altitude (as indicated above, 200 km is the current reference; future studies will determine the final altitude). Figure 13 shows a typical groundtrack on Europa for a 200 km altitude, 75 degree inclination orbit. There is no current plan to maintain a repeating ground track.

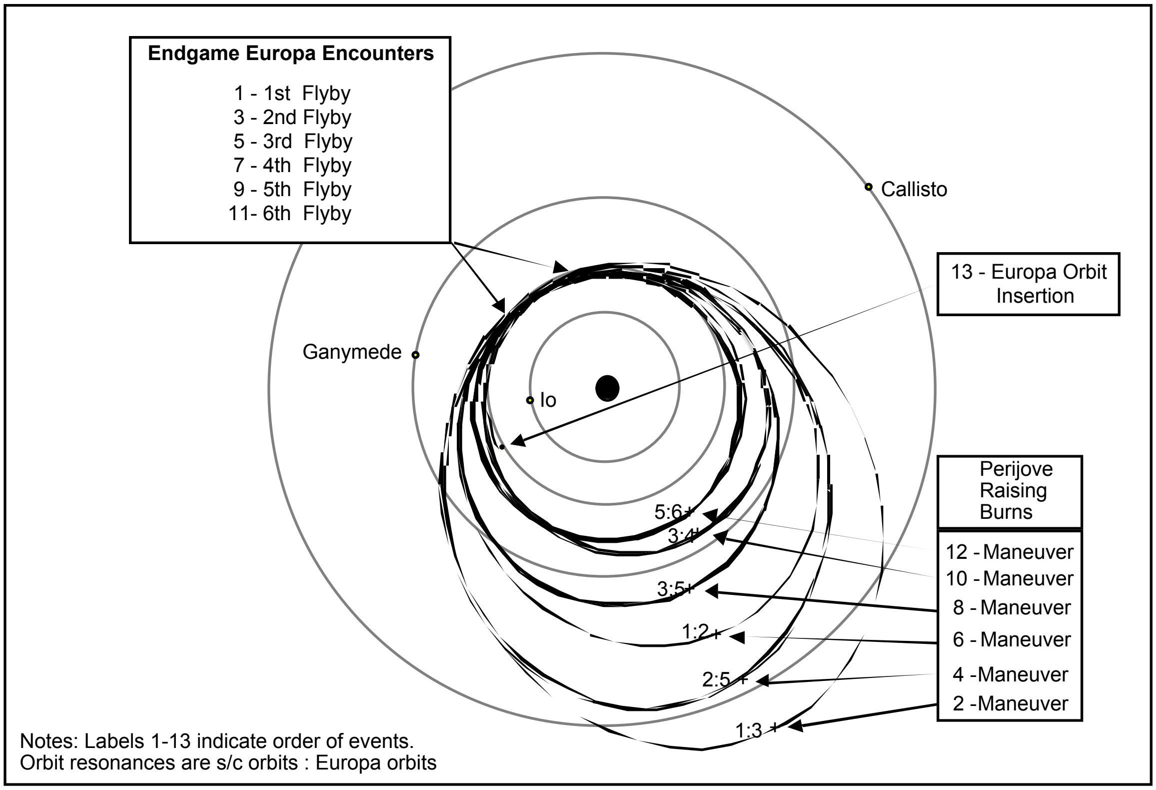

Figure 12. Europa Orbiter generalized endgame trajectory

Figure 14 shows a typical groundtrack on Europa for a possible 45° inclination orbit that might be considered in order to extend the orbit lifetime and thereby mitigate planetary protection requirements.

2.2.1.5 Europa Orbit Science Mission Design

Figure 15 shows one example of how the orbital operations might be conducted in Europan orbit within the scope of the available resources. It is important to note that the chosen science teams are expected to be intimately involved in the design of the actual orbital operations. Additionally, some potential constraints that may be imposed in the actual mission are accommodated in the example. The most important of these is that there is not sufficient power to operate all of the instruments simultaneously. Another, geometrical consideration is the once-per-eurosol (Europan day) eclipse and Earth occultation by Jupiter for as much as 3.5 hours. Spacecraft reaction wheel momentum dumps will be required at least every 3 days and possibly daily.

Table 4. Range of potential Europa final mapping orbit parameters

Parameter	Reference	Likely Range
Altitude (km)	200	100 - 200
Period (min)	137	126 - 137
Inclination (degrees)	83	45, 70 - 88, 93 - 110, and 135
Line of nodes	Ascending node = 310 degrees*	• 10 degrees < Earth/Europa/node (ascending or descending) angle < 80 degrees • Within 20 - 50 degrees of solar meridian
Eccentricity	0.0	0.0 - 0.1
Ground speed (km/sec)	1.19	1.30 - 1.19
Ground track longitude separation at the equator (deg)	9.7	8.6 - 9.9
Ground track separation at the equator (km)	264	237 - 267
Time per orbit S/C is in Earth view (min)	85	85 - 125
Downlink science data volume per Earth-pointed orbit (Mb)	71	71 - 105

* Defined here as the angle measured clockwise from the solar meridian when viewing southward (from Europa's north pole) to the spacecraft's ascending node.

It is envisioned that the interim orbit will provide an opportunity for initial characterization and initial orbital science from all instruments. A to-be-determined duty cycle of nadir-pointed data acquisition and Earth-pointed data downlink will take place during the interim orbit. Short periods of remote sensing instrument operation may be possible during Earth-pointed data downlink periods (e.g., for calibration) within power and data return constraints.

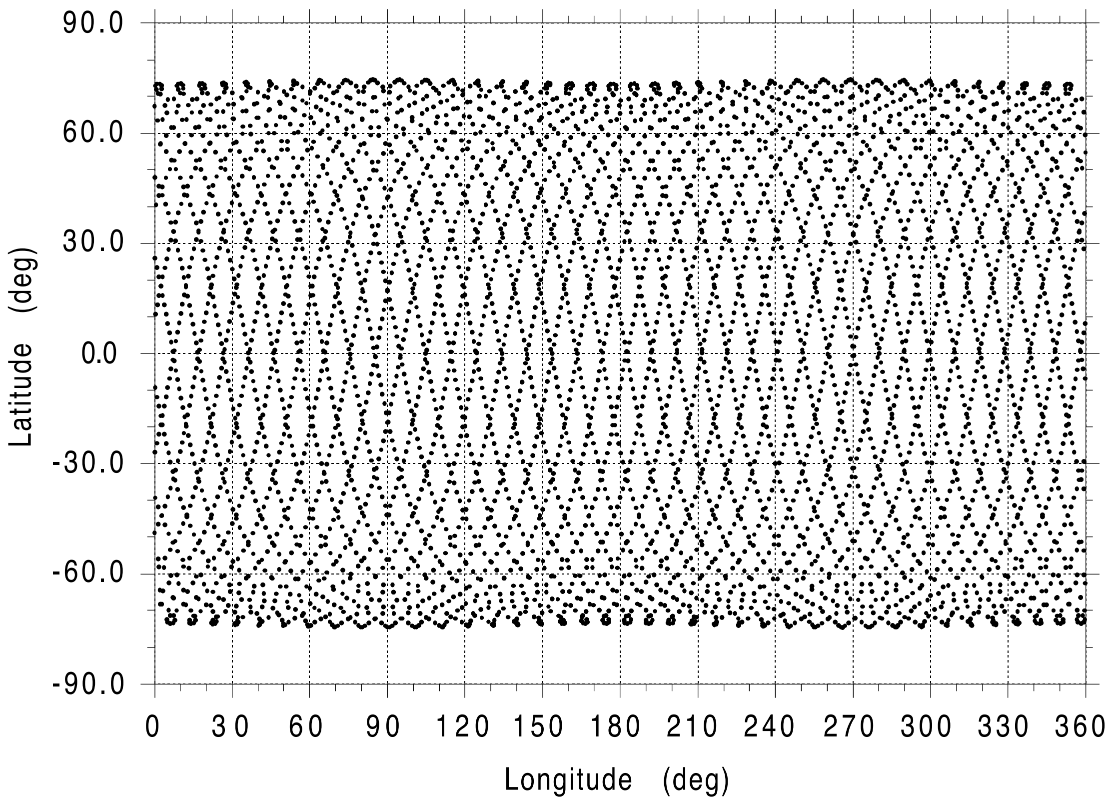

Figure 13. Europa Orbiter ground track (alt = 200 km, i = 75 deg.) -- Europa J_2 and 3rd body effects included. Time span ~3.5 days (near-repeat period).

Following circularization in the mapping orbit, the mission will enter a standard operations phase. Figure 15 shows a nominal 5:6 duty cycle between nadir-pointed orbits and Earth-pointed downlink orbits during this phase.

During this phase, the strawman altimeter, radar, and imaging systems will acquire global coverage of Europa. The average duty cycle is driven primarily by downlink capability. It is expected that the spacecraft transmitter will be turned off during the nadir-pointed science data gathering orbits of this phase to allow sufficient power to be available for the instruments. Note that this mapping scenario is only an example. Proposers are to include their own description of the mapping scenario that best meets the Group 1 science objectives using their proposed instrumentation.

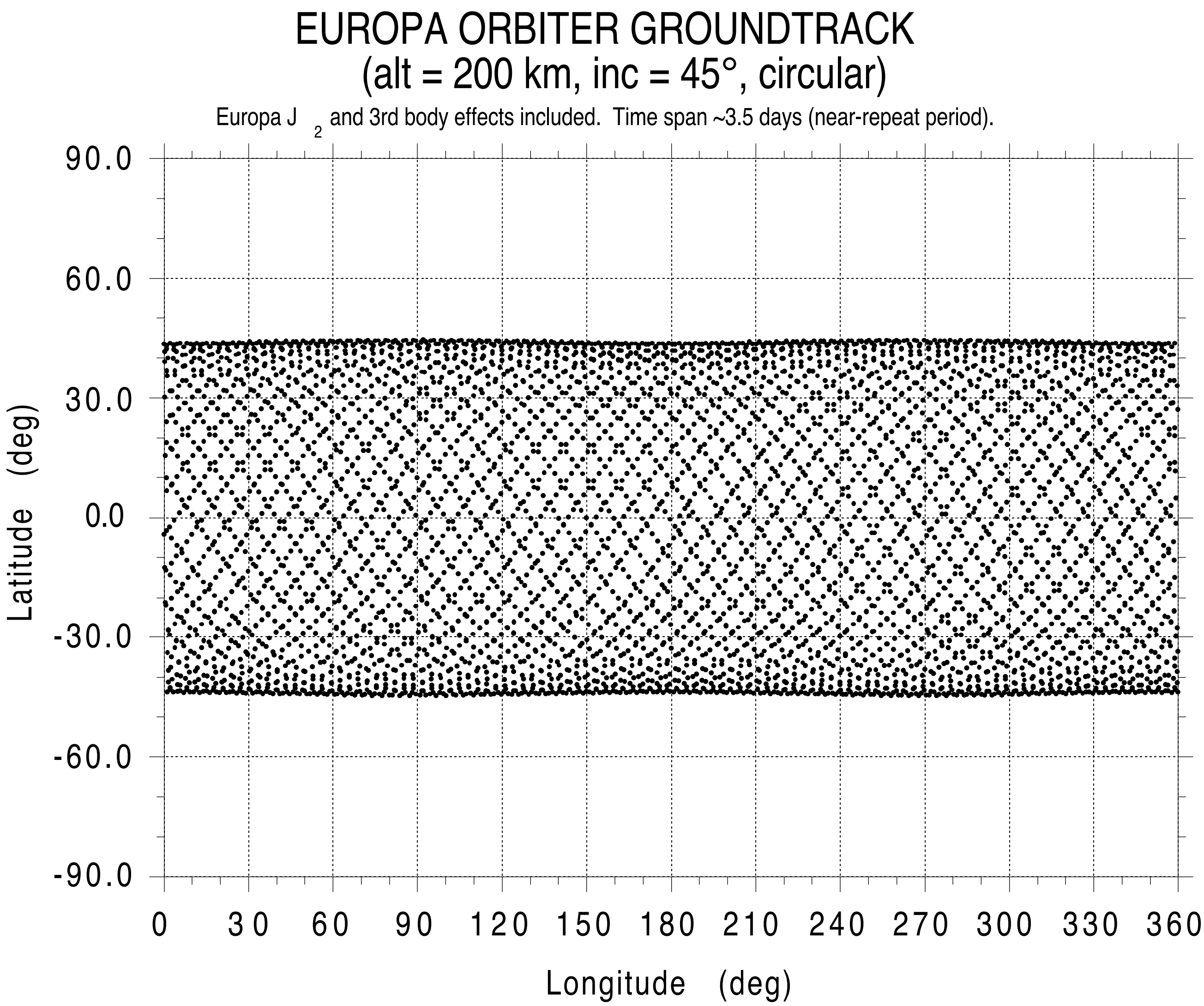

Figure 14. Europa Orbiter ground track for possible, alternative 45° inclination orbit.

If there is sufficient propellant left after the standard operations phase, an orbit altitude lowering may be possible to enable selected high-resolution data taking for all investigations. There are no current plans for any extended mission operations.

2.2.1.6 Orbit Determination Accuracy

It is expected that, once in Europan orbit, there will be some tracking data available on a daily basis. In the first few days of Europa orbital operations, the one-sigma orbital uncertainties projected a few days into the future (for use in observation sequencing) will be of the order of

0.5-2 km in the radial and crosstrack directions and perhaps an order of magnitude worse in the downtrack direction. These uncertainties will diminish rapidly as the Europan gravity field is determined, and the accuracy of predicting the spacecraft's position a few days in the future will be improved by about a factor of 10. The contribution of orbit prediction errors to pointing control error will thus remain no smaller than about 10 mrad along track and 1 mrad crosstrack (one sigma). Post-mission reconstruction of the orbit is ~1m in the radial direction and 10s of meters in crosstrack, one sigma. Downtrack uncertainties will likely be 2 - 5 times the crosstrack values.

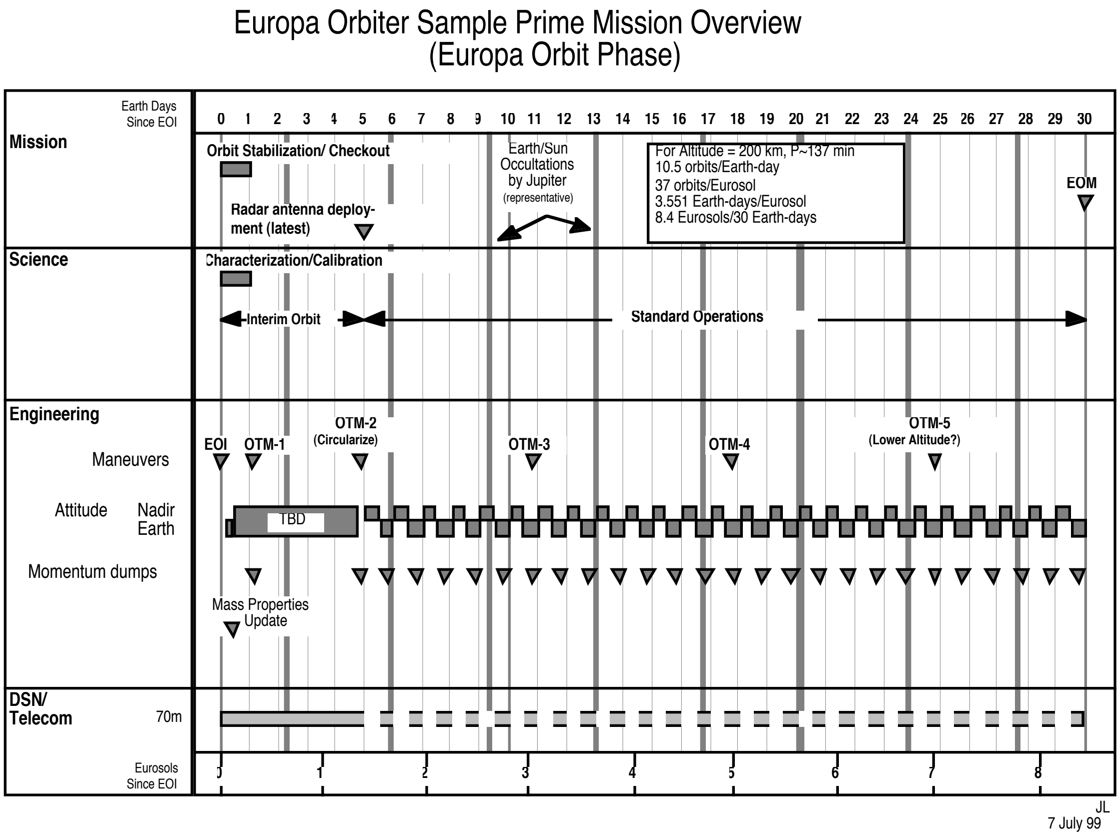

Figure 15. Europa Orbiter sample prime mission overview (Europa orbit phase)

2.2.2 Spacecraft System Design

2.2.2.1 Applicable Standards

The following standards apply:

- The metric system of measurement;
- X2000 Mission Data System standards for software implementation; and
- Reliability, Quality Control, and Safety standards will be tailored to the mission with specific emphasis as appropriate for a long, but resource-limited, mission and in accordance with the project risk management approach.

2.2.2.2 System Overview

The flight system for the reference mission is envisioned to consist of a 3-axis stabilized spacecraft bus that houses the engineering and science electronic subsystems, a high-gain antenna subsystem, a propulsion module, and a proposed Advanced Radioisotope Power Source (ARPS). The actual spacecraft power source is yet to be defined; however, the ARPS creates a more challenging radiation environment to which the science payload should be designed. A view of the spacecraft concept is shown in Figure 16. Instruments are fixed mounted to the spacecraft; there is no instrument pointing platform provided. Instrument pointing is accomplished by maneuvering the entire spacecraft.

The major hardware elements are depicted in Figure 17.

The current approach assumes that a substantial portion of the engineering subsystems will be designed and qualified through the JPL technology development program, X2000. The electronics design will incorporate advanced technologies to allow integration of several functions onto a single substrate. By decreasing the size of the electronics while increasing functionality, the electronics mass will be significantly decreased for the Europa Orbiter mission as compared to previous missions. The integration of the electronics into a small volume will also reduce the mass of the cabling required to integrate these functions. Additionally, the majority of the electronics developed by X2000 will be radiation hardened to 1 Mrad, and, therefore, less additional shielding mass will be required to meet the 4-Mrad requirement for Europa Orbiter.

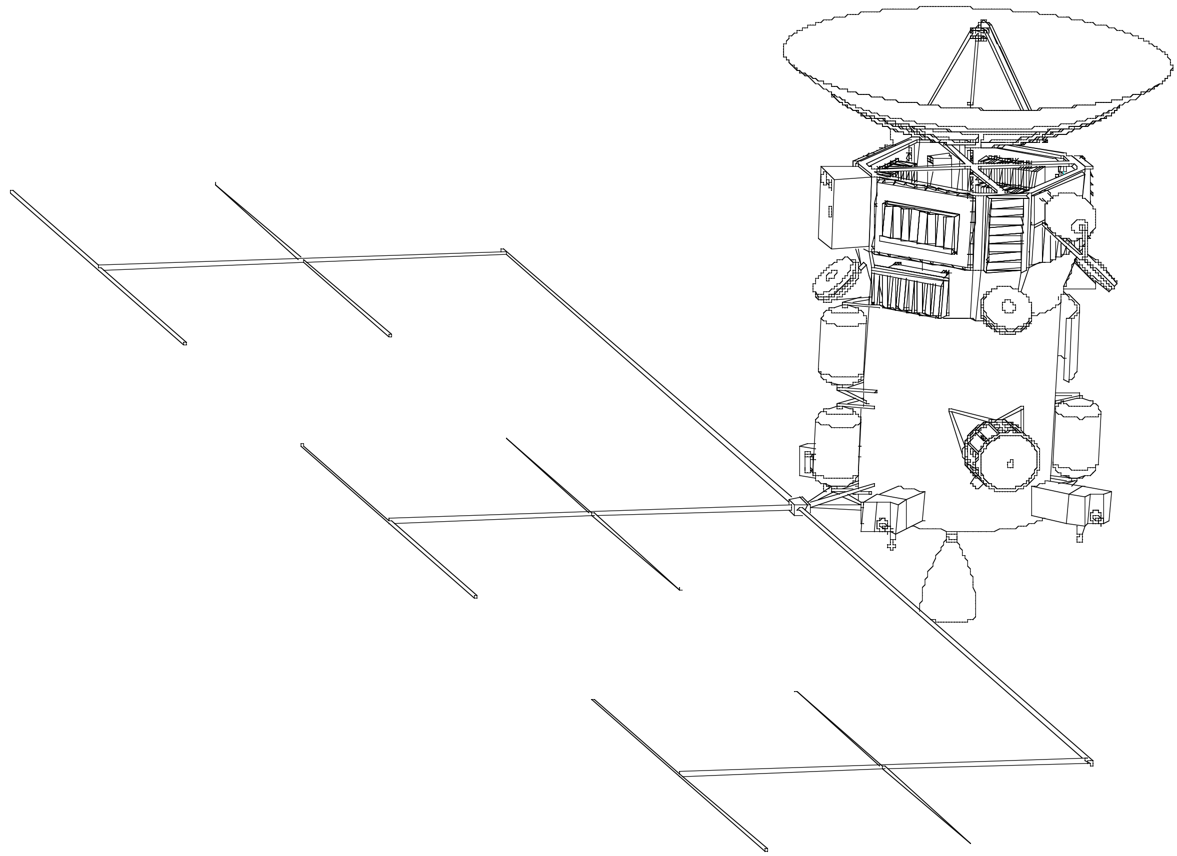

Figure 16. Europa Orbiter spacecraft with Yagi radar antenna deployed

Since X2000 is just getting started and has a very aggressive program, some of their deliverable products may not have the performance envisioned today. Whenever possible, this has been foreseen in this AO by the science allocations identified. As X2000 matures and the final flight performance and components are determined, the flight system and instruments will need to review and finalize the functions and capabilities to be flown. The approach assumed for the integration of the science payload into the engineering system is to minimize the duplication of function and, thereby, allow maximum science return for the minimum mass and power. To achieve this, an integrated team must determine the distribution of functions and requirements between the science payload and the spacecraft engineering system. Concurrent engineering and teamwork between science and spacecraft will be required throughout the design and implementation phase to ensure that cost targets and science objectives are met within the resource constraints of the mission. For the purposes of this proposal, however, the allocations of resources and functions to the science payload specified herein should be assumed.

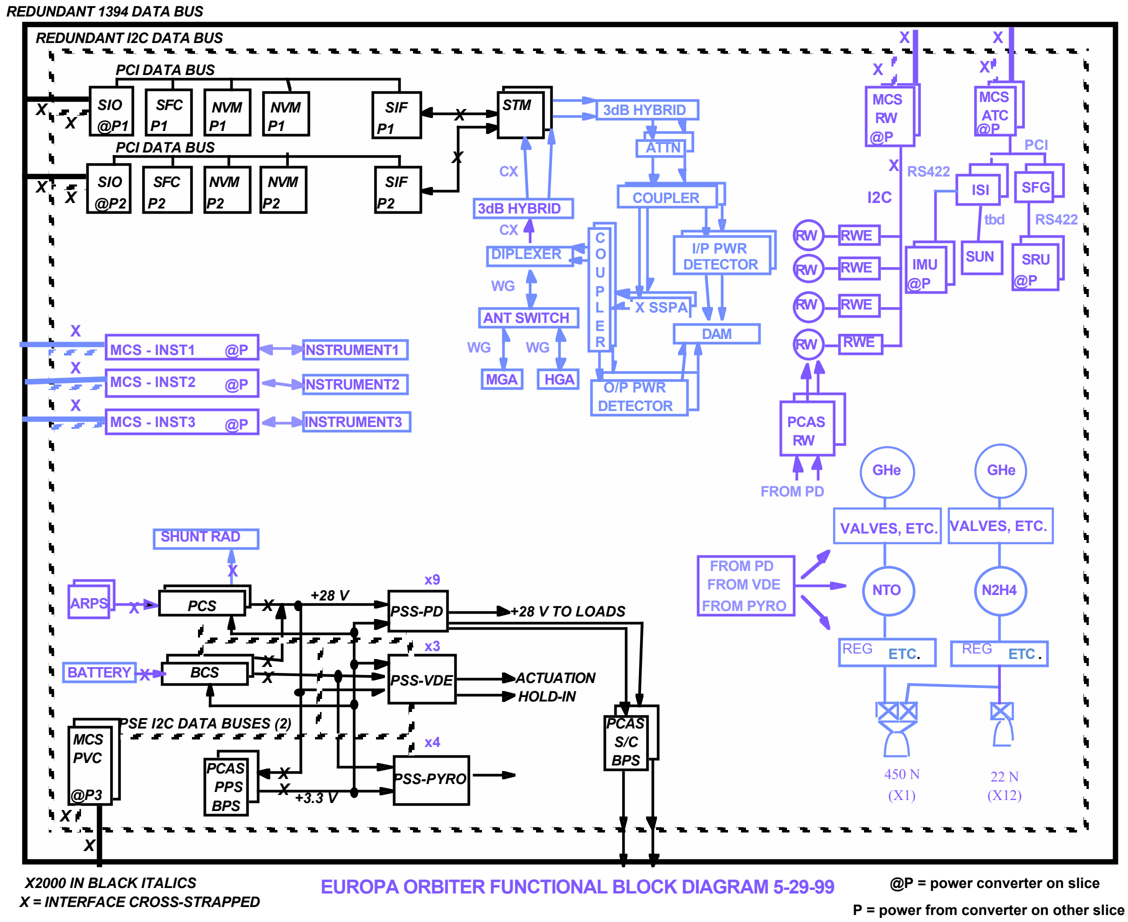

Figure 17. Europa Orbiter functional block diagram.

ACRONYMS & ABBREVIATIONS USED IN FLIGHT SYSTEM BLOCK DIAGRAMS

ANT - ANTENNA

ARPS - ADVANCED RADIOISOTOPE POWER SOURCE

ATC - ACS CONTROLLER

ATTN - ATTENUATOR

BCS - BATTERY CONTROL SLICE

BPS - DATA BUS POWER SLICE

CX - COAX

GHe - GASEOUS HELIUM

HGA - HIGH GAIN ANTENNA

I2C - DATA BUS STANDARD

IMU - INERTIAL MEASUREMENT UNIT

ISI - IMU/SUN SENSOR INTERFACE SLICE

LGA - LOW GAIN ANTENNA

LV - LATCH VALVE

MCS - MICROCONTROLLER SLICE

MGA - MEDIUM GAIN ANTENNA

N - NEWTON

NC - NORMALLY CLOSED PYROVALVE

NO - NORMALLY OPEN PYROVALVE

NTO - NITROGEN TETROXIDE

NVM - NONVOLATILE MEMORY

N2H4 - HYDRAZINE

PCAS - POWER CONVERTER ASSEMBLY SLICE

PCI - DATA BUS STANDARD

PCS - POWER CONTROL SLICE

PCAS - POWER CONVERTER ASSEMBLY SLICE

PD - POWER DISTRIBUTION

PSE - POWER SUBSYSTEM ELECTRONICS

PSS - POWER SWITCH SLICE

PVC - POWER/PDE/VDE MICROCONTROLLER

PYRO - PYRO DRIVE ELECTRONICS

PWS - PLASMA WAVE SPECTROMETER

REG - REGULATOR

RS422 - DATA BUS STANDARD

RW - REACTION WHEEL

RWE - REACTION WHEEL ELECTRONICS

S/C - SPACECRAFT

SFG - STELLAR FRAME GRABBER

SFC - SYSTEM FLIGHT COMPUTER

SIF - STM INTERFACE SLICE

SIO - SYSTEM INPUT/OUTPUT INTERFACE

SRU - STELLAR REFERENCE UNIT

STAR - STELLAR REFERENCE UNIT

STM - SPACE TRANSPONDING MODEM

SUN - SUN SENSOR

VDE - VALVE DRIVE ELECTRONICS

WG - WAVEGUIDE

X - CROSS STRAPPED INTERFACE

X SSPA - X-BAND SOLID STATE POWER AMPLIFIER

2.2.2.3 Mass

The mass of the total science payload exclusive of the consortium radar instrument shall be within the allocation shown in Table 6 (Sec 3.1) including any radiation shielding and reserves.

2.2.2.4 Power

The average power allocated for nonradar science is shown in Table 6 (Sec 3.1). This allocation is a maximum for any given point in time during the mission except for possible short-term contamination prevention. The peak power for the total nonradar science complement may exceed this number, as long as, operationally, the science observations are sequenced so that an average power consumption greater than the allocation is not required over any extended period of time (*e.g.*, longer than five minutes per hour). Power transients up to 100 W for ≤ 50 msec are acceptable.

The spacecraft will supply regulated power between 22 and 36 VDC to the science instruments. Providing other regulated voltage levels and any high-voltage requirements will be the responsibility of the science investigation. Each switched power line will have associated telemetry reporting on/off status, trip status, current level, and output voltage.

2.2.2.5 Volume

The volume allocated to the Europa science instruments is broken into two sets: externally mounted instruments and internal bus instruments (instrument electronics not housed with optics, etc.).

The volume allocated to the externally mounted instrument package(s) is 225 mm x 400 mm x 350 mm, where the mounting interface is 225 mm x 400 mm. The aperture plane can be located on either the 400 mm x 350 mm plane, which is perpendicular to the mounting plane, or on the 225 mm x 400 mm plane parallel to the mounting plane. Radiators can also be located on either of these planes, although the best field of view to space will be on the plane parallel to the mounting plane.

The volume allocated to the internal bus instruments is a 400 mm x 400 mm x 152 mm. Half of this volume is available for the remote sensing instrument electronics that may be housed internally. Although this area can be subdivided, the preference is for all science hardware mounted internally to the bus to be kept in one location.

2.2.2.6 Thermal

All instrument hardware located internally to the bus shall be capable of an allowable flight operating and nonoperating temperature range of -20°C to +50°C.

For the externally mounted instrument(s), the panel interface temperature range is -20°C to +50°C. All thermal dissipation within the external instrument package(s) must be dissipated to space from the instrument housing(s) or radiators. Low-temperature radiators for the science sensors are probably best located on the plane parallel to the mounting plane (if the apertures are also in this plane, the thermal impact of viewing Europa must be compared with the poorer FOV to space on another side). Radiators in any plane are not guaranteed a 100% hemispherical field of view to space (see Section 2.2.2.8).

Any science instrument radiators or temperature-control electrical heaters or coolers necessary for conducting the science investigation are the responsibility of the science investigation. Instruments will be responsible for temperature sensors and heater switches related to the operational performance requirements. The Project will supply temperature sensors and heater switches related to maintaining the instrument within allowable flight temperatures or providing decontamination.

In addition to electrical power, the ARPS thermal dissipation could be utilized to heat the propulsion subsystem. In addition to this waste heat, the spacecraft may utilize Radioisotope Heater Units (RHUs), electrical heaters, louvers, radiators, and thermal blankets for temperature control throughout the spacecraft, including the bus.

The spacecraft thermal design will be capable of maintaining the propulsion subsystem within a 5°C and 50°C temperature range and the bus within a -20°C and 50°C temperature range throughout the mission. The current direct mission trajectory encompasses a solar range of 1 to 5.2 AU.

2.2.2.7 Command, Control, and Data

The spacecraft data subsystem is being developed by the X2000 program and is centered around 2 system flight computers (SFC) shared between engineering and science tasks, such as data processing, editing, compression, etc.

The SFC will control one redundant high-speed and one redundant low-speed data bus. The protocol standard for the high-speed bus is IEEE 1394. The protocol standard for the low-speed data bus is I^2C.

A generic microcontroller will serve as the standard interface between the data buses and remote terminals such as instruments. Each microcontroller will provide interfaces to the four data buses: prime high-speed, backup high-speed, prime low-speed, backup low-speed. Two microcontrollers will be supplied by the spacecraft for use by the selected instrument package. Their characteristics are defined below and in the Description Of X2000 Components Available For Use In Instrument Proposals document of the Outer Planets Program Library, available over the Internet through URL http://outerplanets.LaRC.NASA.gov/outerplanets. Software can be downloaded from the SFC into the microcontrollers for use by the instruments. The mass, power, and cost for these microcontrollers will not be charged against the payload resource allocations of Table 6 in Section 3.1. Any science data processing software that runs on the microcontrollers or the SFC must be supplied and budgeted by the science investigation, however.

Since data acquisition and data downlink do not, in general, occur simultaneously due to mutually exclusive pointing requirements, the spacecraft data subsystem will include bulk data storage. The current baseline design employs nonvolatile flash memory (NVM).

The planned software operating system for the spacecraft is VxWorks. The planned programming language is C^{++}. Additional middleware and other capability to access system services and to support required system interfaces will also be provided.

Tentative key requirements for the total data subsystem are:

System processor speed	>100 MIPS
High-rate bus bandwidth	100 Mb/s
Low-rate bus bandwidth	100 kb/s
Data storage	up to 6 Gbits

Only a fraction of the data subsystem capabilities defined above will be available to support science tasks as reflected in the resource allocations of Table 6 in Section 3.1. The avionics system currently baselined for these missions includes several new technology developments. The allocations listed in this document for science use are derived based on known capabilities of the fallback options that may be used in the event that the new technologies are not available within the time frame required. Thus, these allocations may not reflect the current advertised baseline capabilities. A worst-case fallback option might involve a computer with as little as 30 MIPS processing speed; in that case, multiple computers could be included to meet the science processing allocation. The data subsystem is intended to be compatible with the inclusion of additional memory and/or computing capability within a science instrument.

2.2.2.8 Fields of View

The stray-light field of view (FOV) for the instrument boresights is a minimum of 30^{o} half angle from nominal. Hardware at the edge of the 30^{o} stray light FOV includes the HGA, thermal blankets, radar antenna, and possibly louver assemblies for apertures in a plane perpendicular to the mounting plane. Since materials for these items are still to be determined, worst-case surface optical properties are to be assumed. This worst-case corresponds to apertures in a plane perpendicular to the mounting plane. For apertures in the plane parallel to the mounting plane, the FOV will be greater.

For instrument radiators, the FOV at the mounting plane is a minimum of 30° in any direction. As a radiator surface moves away from the mounting plane, the FOV angle increases. At approximately 350 mm from the mounting surface, the FOV in the current configuration is approximately 60^{o} to 70^{o} in the worst case directions (namely the HGA above and propulsion system blankets below). The surfaces that the radiators will see under operating conditions at Europa are the HGA, thermal blankets, and potentially louver assemblies, if mounted perpendicular to the mounting plane. Although the surface temperatures of these items are extremely cold at Europa, any cryogenic (100 K or less) radiators will be impacted and should be shielded/sized accordingly. Radiators in the 180 K range will have only minor impacts. Since materials for these items are still to be determined, worst-case thermo-optical properties are to be assumed.

2.2.2.9 Coordinate System and Mechanical Design

The flight system configuration, shown in Figure 16, consists of the High Gain Antenna (HGA) assembly, the Science and Avionics Module (SAM), and the propulsion subsystem (PROP). The HGA assembly includes a 2-m reflector, the feed and secondary structure, and may provide the sun sensor mounting interface. The antenna will most likely consist of a composite structure. As the telecom system is further defined, the size of the antenna may be modified.

The spacecraft coordinate system is as shown in Figure 18. The spacecraft Z axis is located through the centerline of the spacecraft with +Z in the main engine nozzle direction. The X-Y plane intersects the Z axis at the interface between the bus/upper shell structure and the propulsion subsystem and oriented with +X in the direction of the instrument boresights.

The SAM houses all of the science equipment (with the possible exception of the Radar antenna) and all of the spacecraft avionics. The four large flat sides of the SAM are referred to as the bus shear panels. These shear panels are where most of the internal bus hardware will be located. The four smaller sides of the SAM are referred to as the frame panels and provide the frame for mounting the shear panels. External bus hardware is ideally mounted on the frame panels, while internal bus hardware can be mounted to the frame panels as needed. The adapter structure seen below the bus provides the transition from the 8-sided bus to the circular interface of the propulsion system. The adapter also provides additional mounting surface for hardware mounted outside the bus. This entire assembly (shear panels, frame panel, and adapter) comprises the Science and Avionics Module (SAM) structure. The shear panels are currently aluminum. The frame, shear panels, and adapter may ultimately be made of aluminum or composite.

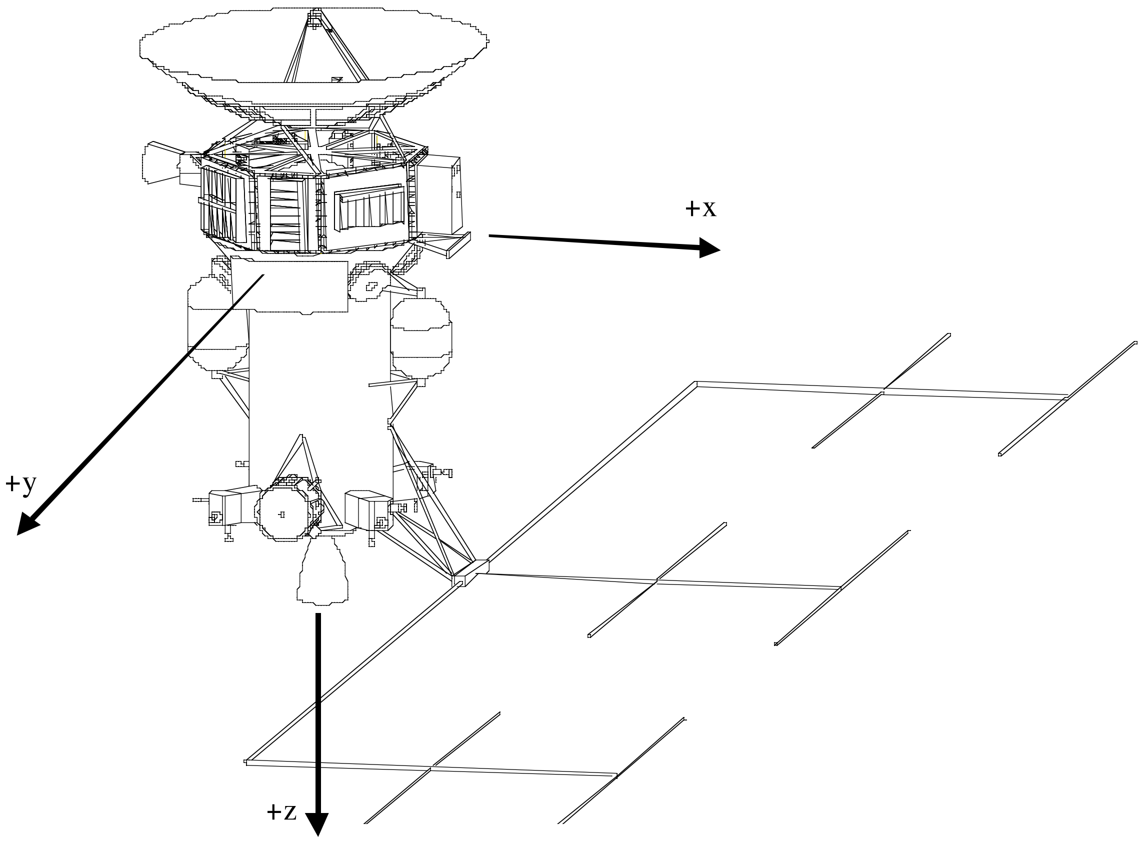

Figure 18. Europa Orbiter spacecraft coordinate system

The optical package is anticipated to be mounted to a frame panel. Figure 19 shows the apertures on the plane parallel to the mounting interface. Although this currently appears to be the most favorable direction for the current spacecraft configuration, this direction is not required. Please note that radiators are not depicted in the optical package cartoon shown in Figure 19.

Any electronics for the optical package that are mounted internally to the bus would be located on a shear plate adjacent to the optical package. PIs are expected to package their science electronics inside the SAM in the same way as the X2000 electronics. X2000 electronics will be packaged in a Compact PCI (CPCI) cage. If science electronics are packaged in CPCI format, then the electronics cage will be provided by the spacecraft, and its mass and cost will be covered by the spacecraft, not by the instrument resource allocation. An example of an EO electronics cage is shown in Figure 20. The cage includes two rows of slices. Backplanes are located in the middle of the cage. If the science electronics use CPCI packaging, the backplane for the science slices is the PIs responsibility, and its mass (~0.5 kg) will be charged to the instrument.

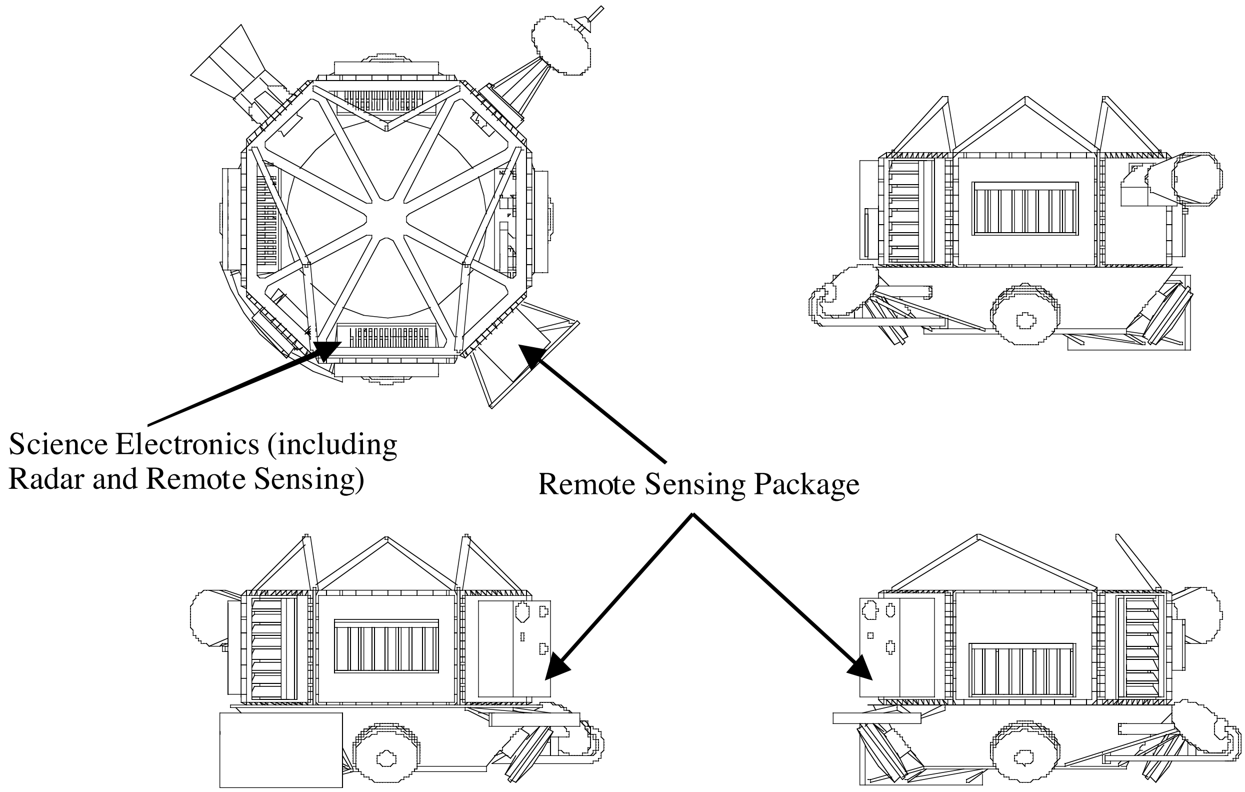

Figure 19. Europa Orbiter Science and Avionics Module (SAM)

Figure 21 gives the format of a CPCI slice. Each electronics slice can have a two-sided board (with thickness of 2.0 mm). Maximum component height is 10 mm on one side and 6 mm on the other side. Front-panel connectors are currently specified as 51-pin and 100-pin micro-D connectors (subject to change). The circuit area is 81.2 mm by 133 mm on each side. The spacing of slices in the cage is 2.032 cm (0.8 inch). Each slice will have wedge locks and heat-sink bars. If a proposer chooses to package their electronics in a format other than CPCI, rationale for that decision must be provided and the associated mass penalties accounted for.

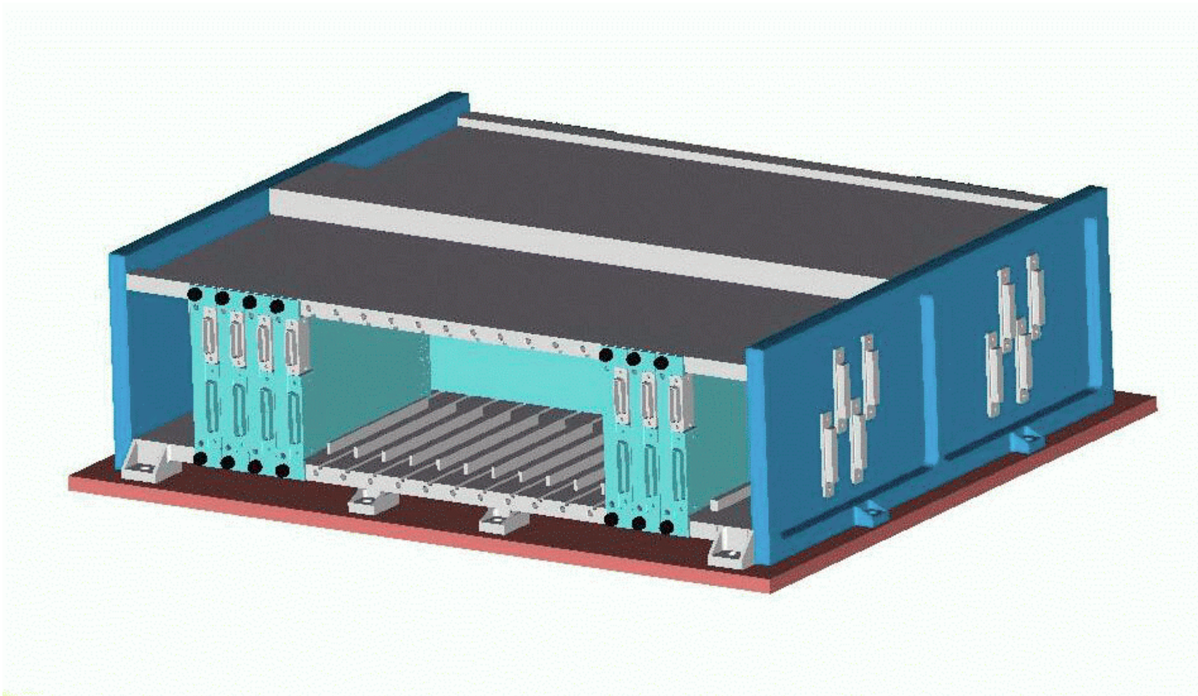

Figure 20. Compact PCI electronics cage. Approximate dimensions are 48 x 40 x 15.2 cm.

A fixed medium-gain antenna (MGA) will also be located on the SAM. It will allow communication during early cruise when the HGA is Sun-pointed and during any spacecraft faults resulting in loss of Earth-pointed attitude.

Below the bus is the propulsion subsystem. The system depicted in Figure 18 is the current propulsion module concept and may change as the configuration matures. The current strawman propulsion subsystem is a dual-mode system consisting of a single hydrazine fuel tank and a single NTO oxidizer tank. These tanks are structurally mounted inside a cylindrical core structure. This core structure also supports all of the propulsion components, the high-pressure helium tanks, and the Advanced Radioisotope Power Source (ARPS).

The flight spacecraft utilizes a linear pyro separation assembly between the base of the propulsion subsystem and the launch vehicle adapter. The main spacecraft load path flows from the bus frame and upper shell structure, through the core propulsion structure and linear separation assembly, to the launch vehicle adapter.

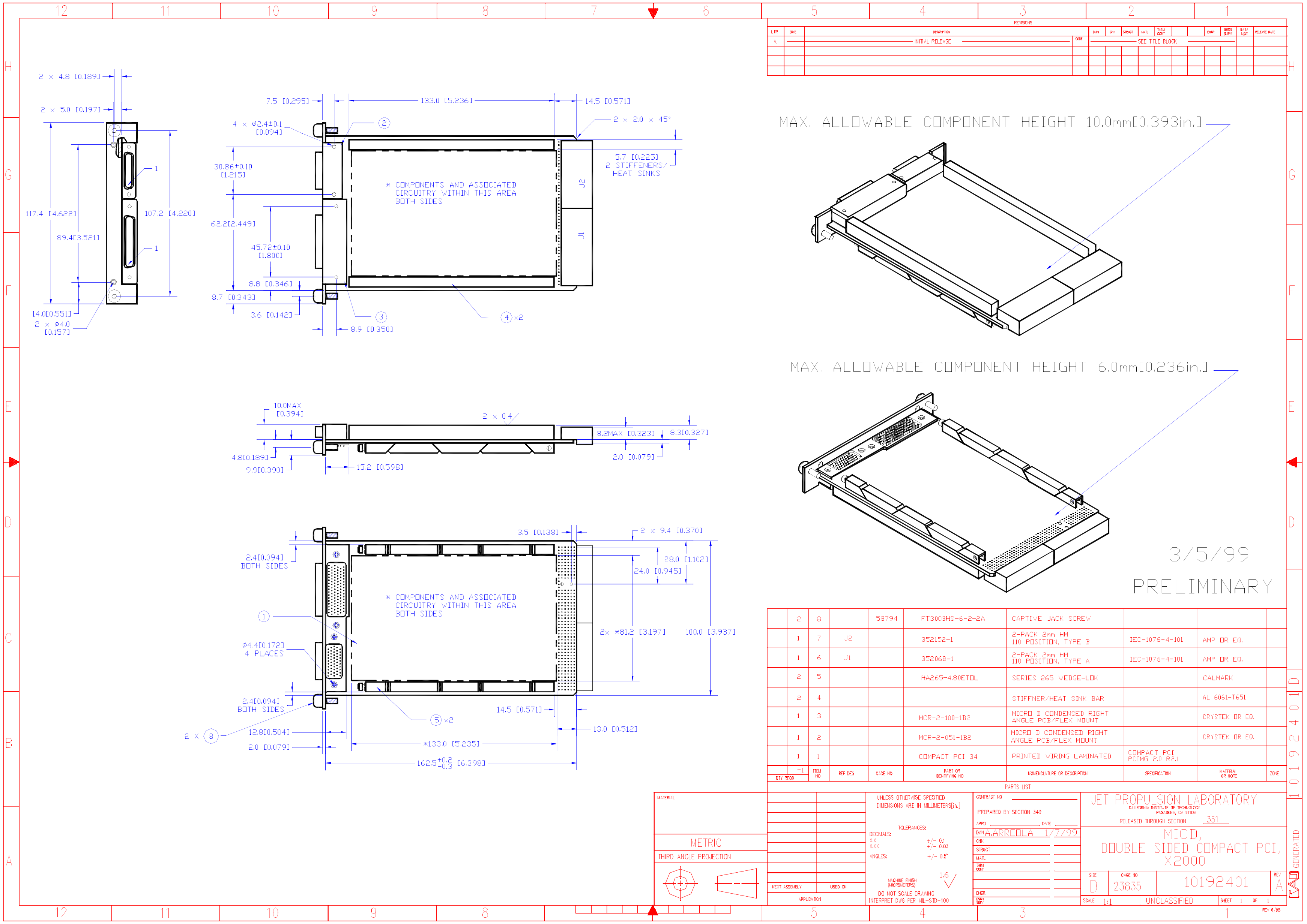

Figure 21. Compact PCI slice format (preliminary, subject to change)

2.2.2.10 Attitude Control

Attitude determination will be done using star trackers, gyros, and a sun sensor. Gyros will be part of a package that includes an accelerometer to measure spacecraft delta-V in a single axis. Attitude control will be accomplished using reaction wheels.

Additional functions of the spacecraft attitude control subsystem are to navigate and control the Star 48V injection kick motor. Roll control during injection will be provided by the spacecraft.

Fine pointing will be accomplished using the star tracker for attitude knowledge. Nearly continuous attitude estimation is planned. The star tracker is required to provide full 3-axis attitude determination.

The gyros will be used principally for maneuvers. The sun sensor will be used principally for attitude acquisition during cruise and faults.

Key baseline capabilities for the overall attitude control subsystem are:

Pointing accuracy (3σ)	5 mrad
Pointing knowledge (3σ)	1 mrad (absolute in inertial hold)
	3 mrad (absolute while slewing)
	0.05 mrad over 0.1 sec (relative)
	0.1 mrad over 1 sec (relative)
	0.4 mrad over 10 sec (relative)
Pointing stability (3σ)	1 mrad in 1 sec
	20 μrad in 10 msec
Maximum slew rate	1.5 mrad/s

Pointing control and knowledge capabilities may be degraded from the above values when the Sun or Jupiter is in the star tracker FOV. Achieving the relative knowledge listed above for 0.1-sec intervals will require non-negligible pointing telemetry data return (of order 1 kbps), which will be charged to the science investigation if this frequency of pointing knowledge updates is requested.

Some to-be-determined settling time will be required after fast slews before reaching the final stability level. In developing science observing sequences, adequate time must be allocated to reorient the spacecraft before and after data downlinking and reaction wheel desaturation sessions. Such maneuvers could take on the order of 30 minutes to execute.

2.2.2.11 Telecommunications

The telecom subsystem for the Europa Orbiter reference mission consists of a 2.0-meter high-gain antenna (HGA), a fixed medium gain antenna (MGA), redundant X-band Solid State Power Amplifiers (SSPA), and redundant Space Transponding Modems (STMs). The HGA is used for normal data downlink. The medium-gain antenna provides communication during early cruise when the HGA is Sun-pointed and during any spacecraft faults resulting in loss of Earth-pointed attitude. In case of emergency, the MGA can also be used to provide very low rate telemetry from the Europa Orbit. A top-level diagram showing the telecom subsystem architecture is shown in Figure 22.

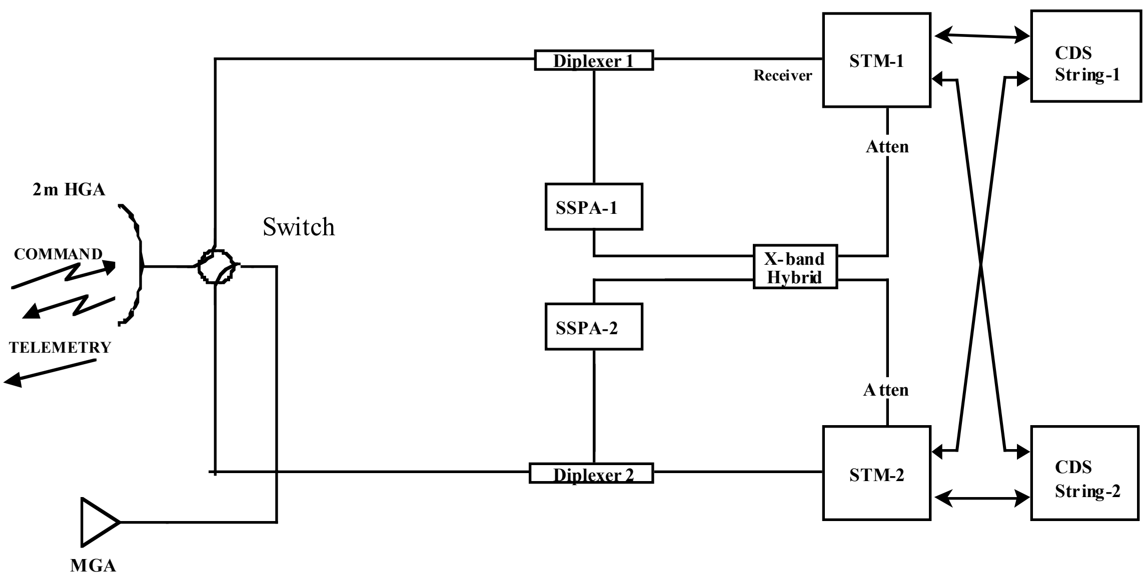

Figure 22. Europa Orbiter telecomm system architecture

The telecommunications configuration shown is a unified uplink/downlink X-band design such that all telecom link functions can be utilized simultaneously.

Since both the DSN and flight system have constant power transmitters, the division of power between simultaneous links will vary depending on specific link configurations. This will affect link performance when supporting multiple links at once. Key communications parameters for the Europa Orbiter mission at 5.2 AU are listed in the table below.

Note that the effective downlink rate allocated for science data return in Table 6 is less due to overhead (packetizing, coding), allowance for radiation degradation effects, engineering telemetry, and reserve.

Parameter	Europa Orbiter	Units
Transmitter Power	≥7.5	Watts
High Gain Antenna	42	dBi-RCP
Medium Gain Antenna	16	dBi-RCP
Science Uplink Command Rate	200	bps
Typical DSN Lockup Time	5	min
HGA Downlink rate (max)	25	kbps

Downlink rate assumes 50% HGA efficiency and a 70-m DSN antenna at 20º elevation angle and 90% weather. A 1-dB spacecraft antenna pointing loss is assumed for the high gain antenna due to ACS control error. Two-sigma margin (approximately 1.5 dB) has been included in the data-rate estimate. The link performance is estimated with no ranging modulation applied on the uplink and downlink. Uplink command rate assumes 70-m DSN transmitting at 20 kW to the HGA and represents the effective transmission rate for science commands (the actual bit rate sent to the spacecraft is substantially higher).

2.2.2.12 Propulsion

The propulsion subsystem will provide the required onboard incremental changes in velocity and reaction attitude control capability for the spacecraft over the lifetime of the mission. The total propulsive delta-V requirement is baselined at 2447 m/s, with a major driver being the requirement to achieve orbit about Europa. The propulsion subsystem is a dual-mode system. JOI and Jupiter maneuvers, including those of the Europa endgame, use the 450-N main engine, which uses NTO and purified hydrazine. Cruise, on-orbit maneuvers, and reaction wheel desaturations use smaller (12 to 22 N) thrusters and purified hydrazine. The system is pressurized with helium, but the main engine mixture control is managed with Variable Liquid Regulators.

2.2.3 Launch Vehicle

2.2.3.1 Launch Site

The expected launch site will be either NASA Kennedy Space Center or the U.S. Air Force Cape Canaveral Station, Florida, USA.

2.2.3.2 Launch Vehicle

The final launch vehicle selection has not yet been made. The reference mission assumes that the Europa Orbiter spacecraft will be designed for launch on the STS/IUS/Star48V launch system. Europa Orbiter will utilize a Jupiter-direct trajectory with a flight time of about 3 years to Jupiter. It is possible that the launch system will be changed to one of the Delta-IV/Atlas V-class plus Star48V upper stage; any such change, and updates to launch environments and other relevant parameters, will be posted in accordance with Sec. 2.11 of the main body of this AO.

2.2.4 Environmental Requirements

Figure 23 shows the best estimate of the integral dust particle fluence on the Europa Orbiter spacecraft over the entire mission.

Table 5 gives the expected fluence of particles with masses and velocities great enough to penetrate 100 mils of aluminum assuming a particle density of 2.5 gm/cm^3. Fluences are shown for surfaces having random orientation in space, orientated normal to the spacecraft velocity vector (+v), and oriented normal to the spacecraft negative velocity vector (-v). Over 85% of the total fluence is accumulated in the first year after launch primarily on surfaces facing the spacecraft velocity direction, which is roughly the +Z direction during cruise to Jupiter. Proposers will need to consider whether or not they need to provide protection for their instruments against such micro-meteoroid impacts.

Other environmental requirements are defined in the Environmental Requirements document of the Outer Planets Program Library, available over the Internet through URL http://outerplanets.LaRC.NASA.gov/outerplanets.

Table 5. Fluence (number/m^2) of 2.5-gm/cm^3 particles on the Europa Orbiter spacecraft that will penetrate 100 mils of aluminum

	Surface Orientation		
Time Period	Random	+v	-v
Entire mission	0.094	0.17	0.0053

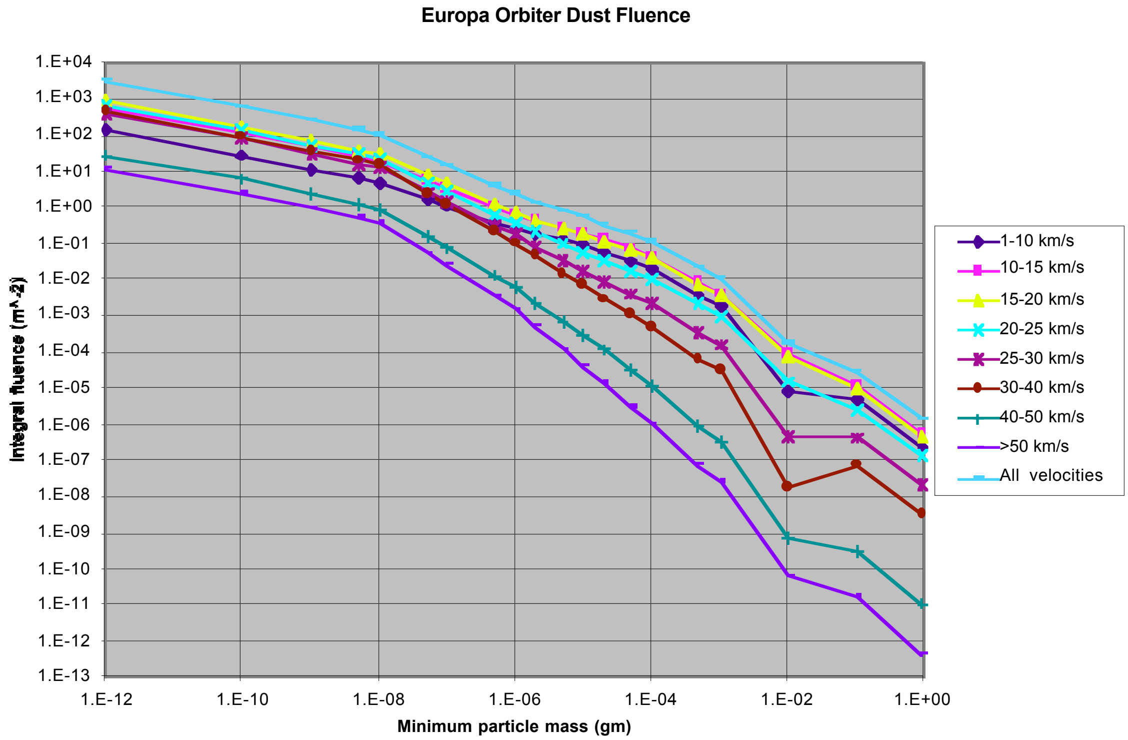

Figure 23. Integral Europa Orbiter dust particle fluence

2.2.5 Planetary Protection Requirements

Preliminary planetary protection requirements are defined in the Europa Orbiter Preliminary Planetary Protection Requirements document of the Outer Planets Program Library, available over the Internet through URL http://outerplanets.LaRC.NASA.gov/outerplanets.

2.3 Mission Development Concept

2.3.1 Flight System Design and Deliveries

Though the three OP/SP spacecraft will be launched over a period of 3-4 years, the initial spacecraft design will be performed by the same personnel assigned to a joint design team. This team will continue into the detailed design of the Europa Orbiter and Pluto-Kuiper Express spacecraft while identifying areas of commonality for incorporation later into the detailed design of the Solar Probe spacecraft. Common subsystem designs will be used wherever possible to minimize the cost of developing and testing each spacecraft.

The OP/SP Project expects to employ the JPL Mission Data System (MDS) as its end-to-end data system. The MDS is currently under development and comprises both flight and ground software used by multimission and project personnel to operate the spacecraft. MDS will be used in software development, system test, and in actual mission operations and will enable the missions to collect, transport, store and act on both commands and telemetry. The MDS software architecture employs an object-oriented approach. The MDS spacecraft component will provide a standard interface to the science instruments including time synchronization, commands, data acquisition and storage, system coordination, fault protection, memory loading, and diagnostic functions. The software architecture is designed such that a core set of software functions are coded and used for all missions. Some mission-specific software will be required to specifically address those unique aspects of each mission, spacecraft, and payload. This core architecture will allow for software reuse, reduced cost in the development and testing of the software, smaller flight operations, faster sequence turn-around times, and improved science return in the event of required failure recovery responses.

Science proposers who intend to exploit available spacecraft computer resources will need to be compatible with the MDS software architecture and design, at least for software that is resident in the Spacecraft Flight Computer (SFC) and Generic Microcontroller. The extent to which any instrument flight software that runs on an internal instrument computer or any investigator-generated ground sequence planning, Ground Support Equipment, or data analysis software will need to adhere to MDS standards will be specified in an OP/SP Software Management Plan. Instrument proposers should plan to have at least one software expert in residence at JPL for at least 6 months prior to instrument PDR for training in the MDS methodology, development environment, and tools. MDS coding will be in C^{++}, and the operating system is VxWorks/Tornado. For the purposes of this AO, it may be assumed that the required software licenses will be provided by the Project. MDS documentation will be provided including a Development Plan specifying the software development process, coding standards, review criteria, and configuration management approach; a Capabilities Catalog describing the capabilities supported by the MDS architecture; and a Users Reference Guide. Science instrument providers will be expected to participate in developing command and telemetry dictionaries, associated system design constraints, associated command elaboration products, and instrument flight rules and constraints.

The planned X2000 First Delivery includes multimission avionics, software, and other equipment for the three missions. The recurring cost for the flight equipment is expected to be comparatively low. The propulsion modules and science packages are unique, however, and they will be a significant factor in the total cost of those missions. These mission-unique costs are borne by each individual mission, but by using common flight support and test equipment and common ground and flight software modules, each mission can reduce its integration and test costs.

The Project will supply to instrument PIs prototype and engineering model microcontroller slices (GMCs, identical to microcontroller slices [MCS] referred to in the spacecraft functional block diagram, Figure 17) for use in simulating the spacecraft interface during their instrument development effort. PIs will need to procure hardware (per Project specifications) that will include a computer workstation (e.g., mid-range Sun), a COTS single board computer (currently assumed to be Power PC based) with an Ethernet interface, and commercial 1394 and I^2C buses to model the spacecraft functions. This hardware, in conjunction with the GMC, will host the MDS flight and ground software system with which the instrument software will need to interface. The Project will supply the MDS software system that is hosted on this hardware. A partial delivery of the Project-furnished MDS software, including the GMC operating system and device drivers, the capability to download code into the GMC, and 1394 and I^2C bus interface code, will be made available by 11/00. A more complete version of the MDS software will become available on 5/01.

Whenever possible, leveraging of technology developments supported by other NASA missions and/or technology development programs will be used where the capabilities match the needs of OP/SP. Such arrangements include incorporation of technologies supported by the New Millennium and Mars Programs. Some mission-unique technology (e.g., heat shield/antenna for Solar Probe) requires that OP/SP wholly support the development.

Standard, reasonable services will be provided the instruments during integration and testing at the system integrator's facility and the launch site. These include:

- Sterile dry N_2 purge (to be connected after receipt at the system integrator). It is the Instrument's responsibility to provide this during shipment and delivery into the integrator's facility.
- Office space with telephones and modem connections
- Laboratory space with limited tool capability in the integration facility.

A Spacecraft Test Laboratory will be developed at the system integrator's facility to simulate the spacecraft and software. The instruments shall provide software simulators of sufficient fidelity as well as breadboards and instrument simulators to support this effort.

2.4 Mission Operations Concept

2.4.1 Integrated Mission Flight Operations Team

The Europa Orbiter, Pluto-Kuiper Express, and Solar Probe missions will share a single core flight team and a common mission data system. This approach is enabled by the common X2000 avionics design shared by all three spacecraft together with a large percentage of common flight software. Each mission will supplement the shared operations capability with a few mission-dedicated personnel including mission planners, instrument representatives, and science investigation teams.

The current plan is for the core flight operations team to be supported by a university-based operations team, which will be competitively chosen in 2001. The university team will be delegated selected routine flight operations tasks to enhance the ability to operate multiple spacecraft simultaneously, to support educational outreach, and to provide a potential source of trained new-hires during the 15 years of flight operations. A workstation-based ground data system design makes implementation of a replica Project Operations Center (POC) at a university cost effective. Science workstations that allow science team members to interact with the operations system from remote sites will be developed as part of the ground data system design.

2.4.2 Beacon Mode Cruise

Routine Deep Space Network (DSN) tracking during cruise will be limited to a single, 4-hour pass every two weeks. This limit on telemetry and radiometric data collection and spacecraft commanding during cruise is intended to keep operations team costs low and reflects the new NASA full-cost-accounting policy, whereby missions are charged for DSN tracking time. To prevent a spacecraft anomaly from going undetected by the ground for a period of up to two weeks, a daily spacecraft beacon monitor track will be performed to establish that the spacecraft is on Earth-point and that no onboard event has been detected that requires ground interaction until the next regularly scheduled telemetry pass. The beacon signal generated by the spacecraft is a subcarrier tone that can be received by a small (5- or 10-meter) ground antenna and detected by a low-cost receiver/detector. The daily beacon monitor check for each spacecraft may be a task delegated to the university operations team.

On-board software that supports Beacon Mode operations includes fault detection and containment software that allows the spacecraft to safe itself during cruise for up to 2 weeks without ground action. Advanced engineering data summarization, onboard alarm limit checking, onboard performance trending, and adaptive anomaly data capture capabilities will also be provided.

The assumption is that science instruments are powered off during cruise except as required for instrument survival. Approximately once a year, or as negotiated with the Principal Investigators, the instruments will be turned on, calibrated, and tested, along with encounter sequence macros that have been developed during the year. Extra DSN tracking during this week will be provided to support the additional commanding and telemetry data collection required.

OP/SP data management and data transport protocols will be X2000 MDS-based and will exploit multimission TMOD data services that will have been upgraded to support the MDS design. The MDS design assumes a common flight/ground file-based data management framework. Files will be used to package and store logical data units (objects) that may not map well into the packet model. The goal is to have management of both onboard data files and ground data files appear similar to the user. File management will support long-popular storage/access capabilities for numerous types of non-telemetry data products. File-based transport protocols will be provided for both spacecraft-to-ground and ground-to-ground nodes. Packetization will be provided as the underlying mechanism of flight-to-ground file data transport. The goal is to make packetization invisible to file-based data management and transport. An implication of this approach is that needed time tags and other ancillary data provided in packet headers and ancillary data packets in the traditional packet-based, data-stream-based systems will have to be provided within the data objects/data files.

2.4.3 Encounter Operations

Transition from cruise operations to encounter operations for the Europa mission starts at JOI - 60 days. Starting at this time, DSN coverage will increase, along with operations team staffing to support higher activity levels and mission critical events. If available within mission constraints, operations resources will be available to support instrument calibration and serendipitous science observations during Jupiter orbits and satellite flybys for the Europa mission. The Europa mission satellite "tour" will be designed to optimize trajectory efficiency to get into Europa orbit rather than to optimize satellite flyby science opportunities.

2.5 Project Schedule

Figure 24 gives the preliminary, top-level schedule for Europa Orbiter mission definition, design, and development.

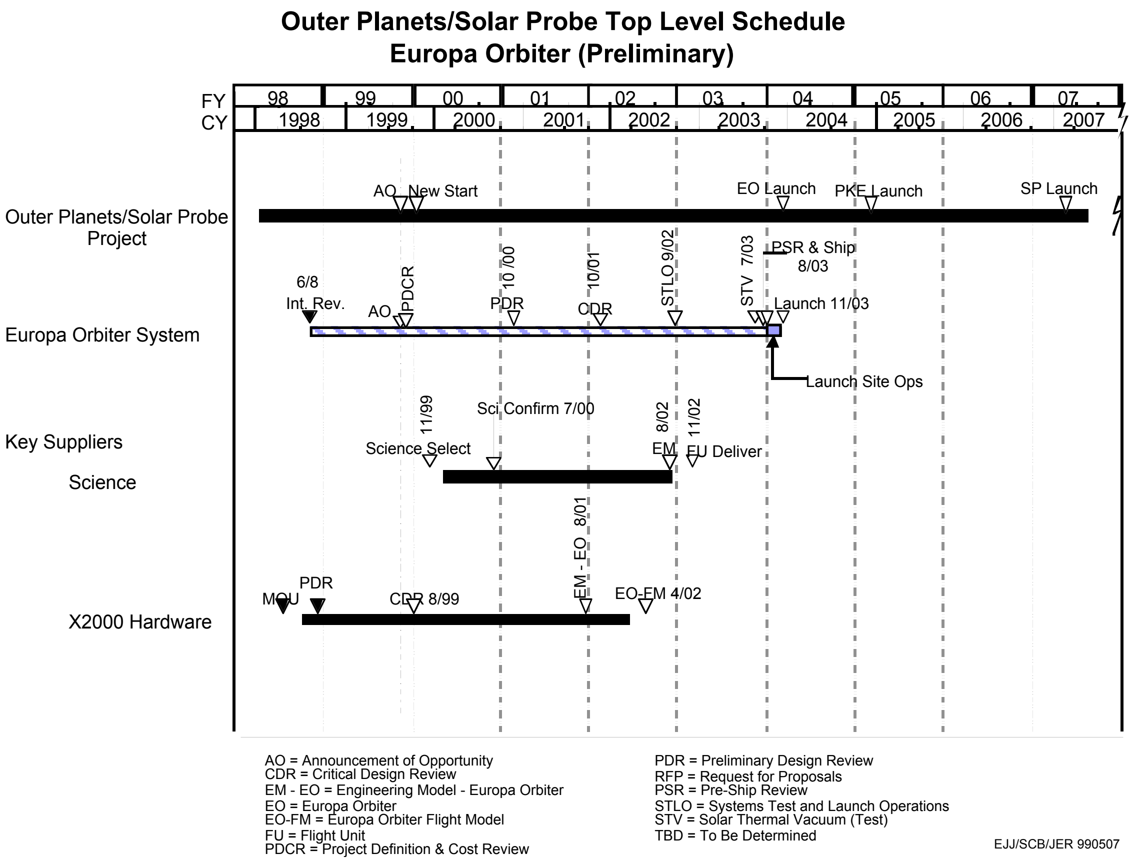

Figure 24. Preliminary top level schedule for Europa Orbiter

3. Science Investigations

3.1 Resources for the Science Investigations

As part of the strawman spacecraft design, an allocation of resources was made for the science payload. Additional details on spacecraft capabilities supporting science are given in Sec. 2.2.2. The computer, bus bandwidth, data storage, and downlink data rate resources must be shared between all of the science investigations.

Table 6 summarizes the key resource allocations for the Europa science payload, including a breakdown between "non-radar" and "radar" science assuming the radar facility instrument is flown. Proposals that fall outside the allocations will have a lower probability of selection.

Table 6. Europa science instrument key resource allocations

		Allocations		
Resource	Units	Non-radar	Radar	Total
Mass	kg	11	9	20
Power (average)	watts	4	20	24
Cost (real yr)	M$	21	9	30
Data storage	Gbits	1.2	1.0	2.2
Computer processing	MIPS	5	25	30
Downlink data rate	kbps	12	2	14
Bus bandwidth (asynchronous)	Mbps	10	20	30
Volume (internal)	cm^3	20x40x15.2	20x40x15.2	40x40x15.2
Volume (external)	cm^3	22x35x40	13100x2600x1	22x35x40

Proposals offering "complete packages" under the definitions 1) or 2) in Section 3 of Appendix B, the Guidelines for Proposal Preparation for the Europa Orbiter Mission, should apply the resource guidelines of "Non-radar" and "Radar," respectively, in Table 6. The only exception is for the external volume in the "Radar" column. No specific volume requirements have been developed, but proposers should imagine a volume more like the one available for the "Non-radar" external volume, mounted where the Yagi antenna is mounted in Figure 16. Other mounting locations can be suggested by the proposer.

Proposals offering "complete packages" under the definition 3) of Appendix B should apply the resource guidelines of "Total" in Table 6. Again, there is an exception in the case of external volume where additional volume in another location would be available. The guidelines of the paragraph above apply.

For proposals that are not offering "complete packages," resource requirements should be the minimum that would permit a scientifically productive investigation, keeping in mind the relative levels of criticality for the resources given in Table 6. Proposers may wish to describe higher performance options for their investigation but should be aware that higher demands on resources will make it less likely that these options could be accommodated.

The power allocation includes power required for instrument heaters for thermal control. Decontamination heaters may exceed this power allocation, but, if so, their use will be limited by power availability. Any instrument purge equipment beyond fittings and internal plumbing that are part of the instrument will not have its mass charged against the above instrument allocations. Any instrument covers must be included in these allocations even if they are jettisoned. Radiation shielding mass must also be included within the mass allocation. If the instrument electronics are packaged in Compact PCI format, they can be housed in a spacecraft-provided shared electronics chassis, and the mass of the electronics chassis will not be charged against the instrument mass allocation. However, the CPCI backplane to the science electronics slices is the PI's responsibility, and its mass (~0.5 kg) will be charged to the instrument.

The power allocation for non-radar instrumentation given in Table 6 assumes that the radar is operating simultaneously. If the radar is powered off, the non-radar power allocation increases to 13 W.

The computer processing allocation in Table 6 is for science use of the SFC. Each dedicated instrument-interface microcontroller could potentially provide additional instrument computing capability subject to power availability constraints. Proposers, however, should not assume that this potential additional computing capability is available in developing their proposals.

The spacecraft data handling capabilities for science are allocated to radar and non-radar in the above table assuming they are operating simultaneously. If only one of these instrument packages is operating during a given period, it could use the combined data handling allocations for both packages. Note that no real-time downlinking of radar or non-radar data is planned; all downlinking is of stored data, and the allocations represent the average rate of downlinking each instrument's stored data over the course of a downlinking period. Science observing scenarios should assume that of the 30 days in Europa orbit, approximately half are dedicated to downlinking with the spacecraft Earth pointed (no remote sensing possible). Because power availability constraints are expected to preclude simultaneous operation of the altimeter and radar, roughly 2/3 of the nadir-pointed time periods should be assumed allocated to altimetry and 1/3 to radar sounding. Imaging can occur simultaneously with both altimetry and radar. All science data acquisition must be restricted to fit within the available data storage, processing, downlink, and power constraints. (Note that the amount of observing time allocated to various investigations should be considered guidelines to be used for the purpose of preparing proposals and will be revisited after payload selection.)

Investigations may exceed the allocated levels of data storage and computer processing MIPS by including the required extra memory or computer as part of their own hardware deliverable. X2000 parts are available for use by science investigators for this purpose as listed in the Description Of X2000 Components Available For Use In Instrument Proposals document of the Outer Planets Program Library, available over the Internet through URL http://outerplanets.LaRC.NASA.gov/outerplanets. The cost and mass to cover use of such parts must be included in the instrument totals.

It is anticipated that teams of approximately six radar science and six gravity science investigators will be selected via this AO and that the science team developing flight instrumentation will be kept small for reasons of efficiency and economy. The total funding guideline in real year dollars to support these investigator teams (over and above the instrument development cost guideline in Table 6) is as follows:

Team	Development phase	Operations phase
Flight instrumentation science	$1.7M	$13.1M
Radar science	$0.9M	$7.0M
Gravity science	$0.9M	$6.1M

The funding guideline for facility instrument Team Leaders and individual Team Members is:

Radar Team Leaders	$0.30M	$2.50 M
Radar Team Member (each)	$0.10M	$0.75M
Gravity Team Leader	$0.30M	$2.00 M
Gravity Team Member (each)	$0.10M	$0.65M

Table 7 gives the funding profile guideline by fiscal year for each investigation (hardware plus science investigators).

The list below summarizes the policies on mass, power, and cost accounting that should be assumed by proposers:

To be charged to science investigations:
- Power converters;
- Electrical thermal control heaters;
- Inflight purge equipment internal to an instrument;
- Instrument covers;
- Instrument radiation shielding;
- Science electronics cards/slices;
- Non-CPCI science electronics housing; and
- CPCI science electronics backplane.

To be charged to the spacecraft:
- Instrument interface microcontroller;
- Inflight purge equipment external to an instrument;
- CPCI science electronics chassis; and
- All RHUs (none permitted internal to instruments).

Table 7. Investigation (instrument and investigators) New Obligation Authority (NOA) funding profile guideline in millions of real year dollars for the development and operations phases

Instrument Development NOA Guideline								
	FY	00	01	02	03	04	Sum	
Non-radar Instruments		3.9	8.0	7.6	1.3	0.2	21.0	
Radar instrument*		2.8	3.4	1.8	0.8	0.2	9.0	
	Total	6.7	11.4	9.4	2.1	0.4	30.0	
Science Team NOA Guideline Development Phase								
	FY	00	01	02	03	04	Sum	
Flight Instruments Team		0.4	0.4	0.4	0.4	0.1	1.7	
Radar Science Team		0.2	0.2	0.2	0.2	0.1	0.9	
	Subtotal	0.6	0.6	0.6	0.6	0.2	2.6	
Gravity Science Team		0.2	0.2	0.2	0.2	0.1	0.9	
Science Team NOA Guideline Operations Phase								
	FY	04	05	06	07	08	09	Sum
Flight Instruments Team		0.6	0.6	1.0	3.0	4.5	3.4	13.1
Radar Science Team		0.3	0.2	0.6	1.5	2.4	2.0	7.0
	Subtotal	0.9	0.8	1.6	4.5	6.9	5.4	20.1
Gravity Science Team		0.3	0.2	0.4	1.5	2.1	1.6	6.1

*these costs reflect only the NASA radar costs and do not include foreign contributions

3.2 Interaction with the Project

3.2.1 Project Fiscal Policy

Following are items pertinent for consideration by proposers in preparation of responses to this AO:

3.2.1.1 Budgetary Authority

NASA will annually allocate New Obligation Authority (NOA) to JPL for the Outer Planets/Solar Probe Project based on an Implementation Plan and updates submitted by the Project. In turn, the Project Office will allocate NOA annually to the Project Work Breakdown Structure primary elements based on the NASA NOA, the plans submitted by the leaders of each element (two of whom are the Chief Scientist and the Flight Instrument Development Manager), and the needs of the Project. Each mission (Europa, Pluto, and Solar Probe) has a Project Scientist, and one of them has additional duty as Chief Scientist. The Science Investigation Principal Investigators whom NASA selects through this AO will negotiate their Statements of Work (SOWs), budget submissions, and authority with the Flight Instruments Development Manager, who will be assisted in these negotiations by the appropriate Project Scientist. The resulting SOW and funding schedule will be documented in a contract between JPL and the PI's institution. This contract will be modified, if necessary, through the course of mission development and operations, covering the period of time from contract award to final delivery of science products after the end of the mission.

3.2.1.2 Mission Budget Environment

Total project costs will be a primary consideration in all design and development decisions and activities. Other requirements will have flexibility and will be prioritized to provide adequate margins and options for staying within cost and schedule constraints.

3.2.2 Project Organization

Overall project leadership and coordination is provided by the Project Manager and Project Office staff. The project is organized as shown in Figure 25. The Chief Scientist is a member of the Project Office staff.

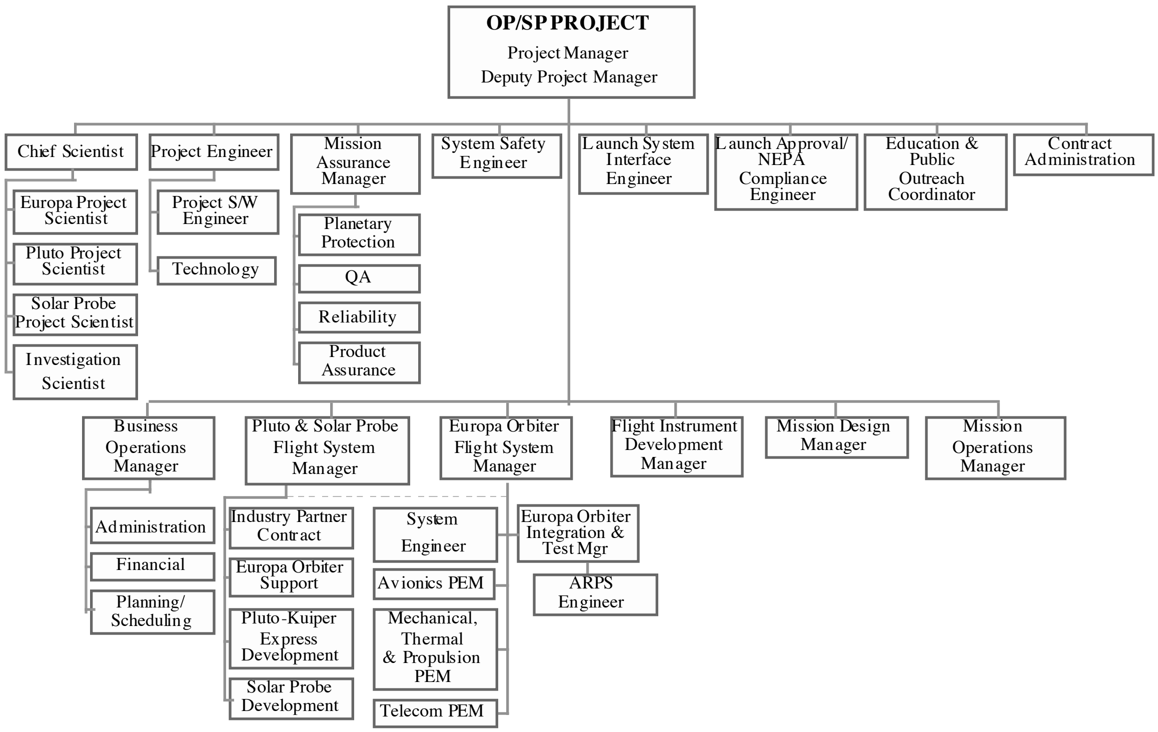

Figure 25. Organization chart for the Outer Planets/Solar Probe Project.

3.2.2.1 Science Investigators as Members of Project Teams

PIs and their lead instrument developers will become members of an integrated implementation team for their respective mission.

Primary interfaces with each mission implementation team will be in the following areas:

1. Trajectory/Navigation/Mission design;
2. Flight System (including mechanical and electronic interfaces, major system trades);
3. Software Development;
4. Mission Assurance (including electronic parts, risk management, quality assurance);
5. Assembly, Test and Launch Operations; and
6. Mission Operations and End-to-End Data Flow (including flight/ground Mission Data System).

The avionics, software, and mission data system for the three missions (and other "customer" missions) will be developed in common by the X2000 First Delivery Project, based at JPL, and their numerous partners and contractors in industry, academia, and Government. Some of the electronic parts developed by X2000 will be available for use in science instruments, such as microcontrollers, memory, and power converters (see the Description Of X2000

Components Available For Use In Instrument Proposals document of the Outer Planets Program Library, available over the Internet through URL http://outerplanets.LaRC.NASA.gov/outerplanets). Each item is intended to be made available commercially and can be considered in the design of the instrument. The OP/SP Project will handle all interfaces with X2000 and will consult with PI teams as appropriate.

3.2.2.2 Relationship Between Science Teams and the Outer Planets/Solar Probe Project

The Project Scientist for Europa will have overall responsibility for the coordination of the mission's science and the achievement of the mission science objectives through chairmanship of the Mission Science Team, the other members of which will be the Science Investigation Principal Investigators and Team Leaders.

Principal Investigators and/or key members of their teams will need to be available for frequent on-line concurrent working sessions. In addition, co-location of key Science Investigation Team members may be required during high-activity periods.

All PI teams will be required to work cooperatively with the spacecraft team to resolve interfaces and requirements and to bring the total flight system capabilities (instruments plus spacecraft) into line with the constraints of the program. This will be accomplished primarily before Science Confirmation but will continue throughout the Development Phase (to launch + 30 days). If individual instruments grow such that their resource allocations are exceeded, science resources will need to be reduced either through contributions from the other instruments, descoping, or cancellation.

As with the mission design, details of the project organization and interactions will evolve over time to meet the needs of the project and mission.

3.2.3 Encounter Science Team Selection, Participation, and Management

The OP/SP development and operations environment will require that individuals selected to produce the science investigations work closely with JPL and other team members on producing investigation hardware, software, mission design, and the flight system which supports the investigations.

After launch and as the spacecraft near their science targets, NASA plans to select via a to-be-determined process a broader team of scientists to provide the expertise required to successfully conduct the observations and reduce, analyze and interpret the data. The core of the team, it is anticipated, will be those who designed the investigations during the prelaunch phase, with possible changes reflecting career moves, retirements, and the evolving knowledge base in planetary and solar science. The intent is to retain the crucial expertise needed to fulfill the science investigation, while bringing in new people who can maximize the value of the science returned from the mission.

3.2.4 Mission Assurance Requirements

OP/SP mission assurance requirements for science instruments can be found in the Instrument Mission Assurance And Safety Requirements document of the Outer Planets Program Library, available over the Internet through URL http://outerplanets.LaRC.NASA.gov/outerplanets.

3.2.5 Principal Investigator and Team Leader Responsibilities

Science instrument Principal Investigators (PIs) are responsible for instrument design and development, fabrication, test, calibration, and delivery of flight hardware, software, and associated support equipment, within project schedule and payload resources. The PIs are responsible for planning and operational support of instrument operation, data analysis and overall conduct of each of their investigations.

NASA anticipates that a PI-funded instrument engineer will attend reviews and interface meetings and maintain the instrument Interface Control Document as a normal course of doing business. No sustained stay at the spacecraft integrator's site is required prior to flight unit delivery. Extended support at the spacecraft integrator's or the launch site may be necessary depending on developments during integration and test activities.

The specific responsibilities of the instrument PI include, but are not limited to, the following:

1. Developing an internal management plan and an experiment implementation plan;
2. Ensuring that the design, fabrication, development, and testing of the investigation flight elements are appropriate to the objectives of the investigation and assure qualification to the environmental and interface constraints;
3. Managing hardware and software margin to ensure successful integration and implementation of the experiment;
4. Hardware and software quality assurance and reliability and selection of parts and materials;
5. Ensuring that instrument hardware and software development meets the approved schedules and cost plans;
6. Establishing requirements, Interface Control Documents (ICDs), schedules, and transfer of funds through negotiation with the Project;
7. Ensuring the flight hardware is flight qualified and properly calibrated;
8. Participating in Project Science Group (PSG) meetings and associated working groups. PSG meetings will be held in conjunction with PI Working Group meetings every 6 months;

9. Conducting payload reviews;
10. Participating in Software Working Group (SWG) meetings, as required by the proposed science use of spacecraft computational resources and services to resolve requirements, process issues, and interface issues and to resolve resource allocations and operational timelines;
11. Supporting payload integration and system test procedure development and maintenance and payload hardware and software integration;
12. Participating in flight system tests and integrated end-to-end ground system tests and operation of any payload-unique Ground Support Equipment (GSE) in these tests;
13. Supporting definition of mission database contents, including, but not limited to, flight rules and constraints, sequences, payload telemetry, and commands;
14. Supporting integrated mission data/sequence development and flight software integration;
15. Supporting launch site operations planning, including safety, and launch site system tests at Kennedy Space Center/Cape Canaveral Air Force Station;
16. Planning and executing mission operations;
17. Ensuring that the reduction, analysis, reporting, and archiving of the results of the investigation meet with the highest scientific standards consistent with budgetary and other recognized constraints; and
18. Preparing, certifying and releasing a final data product (to PDS) within six months or less of data receipt on the ground.

The specific responsibilities of the Science Team Leader include, but are not limited to, the following:

1. Developing an internal management plan and an experiment implementation plan;
2. Establishing requirements, schedules, and transfer of funds through negotiation with the Project;
3. Participating in Project Science Group (PSG) meetings and associated working groups. PSG meetings will be held in conjunction with PI Working Group meetings every 6 months;
4. Supporting definition of mission database contents, including, but not limited to, flight rules and constraints, sequences, payload telemetry, and commands;
5. Supporting integrated mission data/sequence development and flight software integration;
6. Supporting launch site operations planning, including safety, and launch site system tests at Kennedy Space Center/Cape Canaveral Air Force Station;
7. Planning and executing mission operations;
8. Ensuring that the reduction, analysis, reporting, and archiving of the results of the investigation meet with the highest scientific standards consistent with budgetary and other recognized constraints; and

9. Preparing, certifying, and releasing a final data product (to PDS) within six months or less of data receipt on the ground.

The specific responsibilities of individual Science Team members include, but are not limited to, supporting and assisting the Team Leader in carrying out his/her responsibilities.

3.3 Deliverables

3.3.1 General

The deliveries by the instrument Principal Investigator to the Project include, but are not limited to, the following:

1. Sign a Memorandum of Agreement with the Project that documents resource allocations;
2. Provide and maintain required documentation, including ICDs (see Sections 3.3.3 and 3.5.4);
3. Support development and maintenance of ICDs;
4. Provide monthly Technical Progress Reports and monthly Financial Management Reports;
5. Deliver flight-qualified hardware to the flight system integrator with suitable shipping containers and any protective covers required;
6. Deliver to the flight system integrator one of the following items: a) an Engineering Model, b) a Protoflight unit, or c) a payload mechanical fit-check model and payload data interface simulator (this unit is to allow testing of the transfer of command and telemetry data with the spacecraft bus and a mechanical fit check between the instruments and the spacecraft);
7. Provide necessary payload-unique GSE for stand-alone integration and launch operations;
8. Provide payload unit history logbooks including power-on time log;
9. Deliver investigation flight software to be resident in the spacecraft flight computer (see Section 3.3.3);
10. Provide timely information to establish and maintain controlled baselines for software interfaces, shared computational resources, mission data, and mission operations timelines and sequences; and
11. Archival science data products.

The deliverables by the science Team Leader to the Project include, but are not limited to, the following:

1. Sign a Memorandum of Agreement with the Project that documents resource allocations;
2. GDS/MOS requirements document inputs; and
3. Archival science data products.

Individual science team members will support and assist the Team Leader in producing his/her required deliverables.

3.3.2 Hardware Delivery

The payload data interface/mass simulator, Engineering Model, or Protoflight unit must be delivered to the flight system integrator's site on or before 15 months before launch. The science payload flight units must be delivered on or before 12 months before launch. Payload flight units must be accompanied by all ground support equipment needed to support system test. Unit history logbooks shall accompany the flight hardware. Payload flight units must be fully qualified and calibrated before delivery; instruments will not be returned again to the PI.

3.3.3 Software

The OP/SP Software Management Plan will specify requirements on software documentation, testing, source materials, reviews, and metrics.

3.3.3.1 Software Documentation - Software Interface Control Document (ICD)

Initial definition of operational timeline requirements and related resource demands (characterized by peak and typical parameters) will be negotiated in compliance with resource usage constraints placed on the science payload by the Project and documented in an Initial Software ICD for:

1. Volatile and nonvolatile memory;
2. Observational activity and data processing algorithm frequency and duty cycle;
3. Storage demands with storage durations; and
4. I/O requirements for all classes (data bus bandwidth, command/telemetry bandwidth) including best available information on compliance with protocol standards or any unique data transfer methods.

Updated information for all items in the Initial Software ICD, with projections of final commitments for all resource demands, plus protocol compliance for all transactions using the spacecraft C&DH, including behavioral characteristics of timing where it is relevant to correct operations of the science payload/mission, is due with the Update Software ICD.

The committed baseline for all elements of the Software ICD is the third delivery, due with the Final Software ICD.

3.3.3.2 Software Documentation - Other

Requirements, design, build, test, and evaluation information that provides insight into the software implementation should be provided as it becomes available, in accordance with the PI's normal development plan.

3.3.3.3 Software Test: Required Evaluation Procedures

Software test procedures are required and are subject to approval. The fidelity of the procedure and level of approval corresponds to the potential risks involved in the procedure. Generally, as the software testing is done in primarily a simulation and Engineering Development Unit (EDU) environment, the risk is minimal, requiring approval from only the cognizant personnel for the item under evaluation and Spacecraft Test Laboratory (STL) operations. Circumstances that may require further approvals include:

1. Use of flight hardware in the configuration;
2. Requirements for special interfaces - either hardware or software - that may require test setup and verification; and
3. Exclusive operations or continuous operations that produce resource conflicts not reconcilable among other parties.

3.3.3.4 Software Source Materials

The mission load (all executable spacecraft and payload flight software and data) is generated as an integrated load image, including initial/nominal values for all updatable mission data/system files. To develop the mission load, source code for compilation, materials for binding, and data/file load shall be provided in a timely fashion to support software development integration in the Spacecraft Test Laboratory, assembly and integration tests during science payload integration, and mission readiness tests at the launch site. The Final Software Baseline Delivery for launch is scheduled at the time of flight hardware delivery, prior to the start of science integration for final build and characterization of the launch configuration load image. Other postlaunch flight software updates are expected.

3.4 Payload Reviews

The payload PI(s) and science Team Leaders will be expected to attend the spacecraft Preliminary Design Review (PDR) and Critical Design Review (CDR), ground system reviews, and any informal reviews scheduled by integrated development teams with payload participation requiring the PI rather than the instrument engineer.

Each instrument PI will host a Preliminary Interface Requirements and Design Review (PIRDR) for their investigation. The PIRDR is scheduled as early as possible after the completion of the Functional Requirements Document (FRD)/Experiment Implementation Plan (EIP). Topics include: discussion of the EIP, discussion of the FRD, description of interfaces, interface verification plan, and description of the safety plan.

Likewise, each PI will host a Final Interface Requirements and Design Review (FIRDR). The FIRDR occurs prior to the mission CDR, at the completion of the payload detailed design. Topics include: status of hardware design, fabrication, test, and calibration, software design and test plans, plans for integration, description of support equipment, finalization of interfaces, command and telemetry requirements, and discussion of environmental and system tests.

Prior to delivery of the flight instrument, each instrument PI will hold a Hardware Requirements Certification Review (HRCR) to ensure that the instrument meets all of its requirements and is ready to be shipped for integration on the spacecraft.

3.5 Documentation Requirements

The following is a list and description of the minimum formal documentation that will be required from instrument PIs:

1. Memorandum of Agreement;
2. FRD/EIP/Safety (Combined);
3. GDS/MOS Requirements (Preliminary and Final);
4. ICD Major Milestones:
    - Preliminary Physical;
    - Initial Software;
    - Final Physical (start configuration control);
    - Update Software; and
    - Final Software;
5. Instrument Design Description (IDD);
7. Payload Handling Requirements List;
8. Unit History Log Books; and
9. Acceptance Data Package

Science Team Leaders must provide:

1. Memorandum of Agreement; and
2. GDS/MOS Requirements (Preliminary and Final)

Individual science team members will support and assist the Team Leader in generating these documents.

3.5.1 Memorandum of Agreement

A Memorandum of Agreement documents the investigation resource allocation (mass, power, volume and fiscal resources) between the project and each investigation PI and Team Leader. This is written immediately after payload selection and signed by the Project Manager, PI or Team Leader, and spacecraft flight system integrator designee for hardware investigations.

3.5.2 Functional Requirements Document (FRD)/Experiment Implementation Plan (EIP)/Safety Plan

Each instrument PI is responsible for writing a combined Functional Requirements Document and Experiment Implementation Plan for their investigation within 3 months of selection. Contents are negotiated with the project manager, but may be assumed to include:

1. Payload functional requirements;
2. Hardware development-and-test plans and schedule, including reliability and quality assurance plans;
3. Software development-and-test plans and schedule;
4. Cost plan for hardware and software development, fabrication, test, and calibration from selection through launch;
5. Margin management plan;
6. Post-launch cost plan for instrument operation, data analysis, and data archiving;
7. Requirements for project support;
8. Personnel and hardware safety plans;
9. Contamination control plan;
10. Calibration plans;
11. Science management and investigation plan;
12. Payload portion of range safety plan and payload safety at launch site; and
13. Fracture control plan (for Space Shuttle launched payloads).

3.5.3 Ground Data System (GDS) / Mission Operations System (MOS) Requirements

Ground Data System / Mission Operations System requirements due dates are listed below. These primarily address instrument operation requirements and flight rules.

	Europa	Pluto	Solar Probe
Preliminary	9/00	9/01	9/04
Final	9/02	9/03	9/06

3.5.4 Physical Interface Control Documents (ICDs)

Physical ICDs are negotiated directly with the spacecraft engineering team in an integrated-development-team environment, with Preliminary Physical ICDs required by the spacecraft PDR and final Physical ICDs under configuration control by the spacecraft CDR. Physical ICDs identify all payload interfaces, including, but not limited to, the volume envelope, mounting, center of mass, electrical and mechanical connections, end circuits, pyro devices, features requiring access or clearance, purge requirements, testing, facility support, view angles, clearances, etc.

3.5.5 Instrument Design Description Document (IDDD)

The final design of the payload is documented in an IDDD. The IDDD is due at the HRCR. Included in the IDDD is the parts and materials list.

3.5.6 Payload Handling Requirements

A payload handling requirements list must be supplied prior to the delivery of flight units to the spacecraft integrator. This checklist describes any special handling necessary to ensure the safety and planetary protection requirements of the flight hardware.

3.5.7 Unit History Log Book

The Unit History Log Book accompanies the delivery of the flight hardware.

3.5.8 Acceptance Data Package

The Acceptance Data Package includes (but is not limited to) final drawings, documents, mass properties, qualification data, footprint drawings, final power, etc.

3.6 Key Prelaunch Delivery Dates

Activity	Due date
Contract execution	1/00
FRD/EIP	4/00
Science Confirmation	7/00
PIRDR	8/00
GDS/MOS requirements - preliminary	9/00
Physical ICD - preliminary	10/00
Software ICD - initial	10/00
Mission PDR	10/00
FIRDR	4/01

Software ICD - update	4/01
Physical ICD - final	10/01
IDD - preliminary	10/01
Mission CDR	10/01
Flight S/W for SFC - preliminary	8/02
Software ICD - final	8/02
S/W test procedures	8/02
SIM, EM or PFM delivery	8/02
GDS/MOS requirements - final	9/02
IDD - final	10/02
HRCR	10/02
Flight Unit delivery	11/02
Unit history logs	11/02
Flight S/W for SFC - final	11/02
Payload handling requirements	11/02
Acceptance data package	11/02
Launch	11/03

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